INFORMATION SHEET

The U.S. Nuclear Regulatory Commission's Public Scoping Process on Environmental Issues Pertaining to Decommissioning Nuclear Power Plants

The U.S. Nuclear Regulatory Commission (NRC) is gathering information necessary to prepare a supplement to the *Final Generic Environmental Impact Statement of Nuclear Facilities*, NUREG-0586, for power reactors only. The NRC is interested in public comments on environmental issues and the proposed scope of the staff's environmental review.

Written comments can be submitted by e-mail to DGEIS@NRC.GOV or to the following address postmarked no later than July 15, 2000:

Chief, Rules and Directives Branch
Division of Administrative Services, MS T-6D 59
U.S. Nuclear Regulatory Commission
Washington, D.C. 20555-0001

For additional information, contact Dino C. Scaletti, NRC Senior Project Manager, Decommissioning Section, Project Directorate IV & Decommissioning, Division of Licensing Project Management, Office of Nuclear Reactor Regulation, U.S. Nuclear Regulatory Commission, MS 0-11D19 Washington, DC 20555-0001, or at 1-800-368-5642, ext. 1104.

NUREG-0586

Excerpted Sections
Relating to Power Reactors

Final Generic Environmental Impact Statement
on decommissioning of nuclear facilities

U.S. Nuclear Regulatory Commission

Office of Nuclear Regulatory Research

August 1988

FOREWORD
BY
NUCLEAR REGULATORY COMMISSION STAFF

The NRC staff is in the process of reappraising its regulatory position relative to the decommissioning of nuclear facilities. The initial part of this activity consisted of obtaining the information base to support any subsequent regulatory changes. Highly detailed studies were completed, through technical assistance contracts of the technology, safety and costs of decommissioning various nuclear facilities. (These studies are referenced in this document). These studies were, in turn, utilized along with other information, to prepare a Draft Generic Environmental Statement on Decommissioning Nuclear Facilities, draft GEIS, NUREG-0586, January 1981. On February 11, 1985, the Commission published a notice of proposed rulemaking on decommissioning criteria for nuclear facilities (50 FR 5600).

This Final Generic Environmental Impact Statement on Decommissioning Nuclear Facilities is being published based on public comment on the draft GEIS and on the proposed rule as well as on updated information in the technical information base. This statement is required because the regulatory changes that might result from the reevaluation of decommissioning policy may be a major NRC action affecting the quality of the human environment.

The information provided in this Statement, including any comments, will be included in the record for consideration by the Commission in establishing criteria and new standards for decommissioning.

ABSTRACT

This final generic environmental impact statement was prepared as part of the requirement for considering changes in regulations on decommissioning of commercial nuclear facilities. Consideration is given to the decommissioning of pressurized water reactors, boiling water reactors, research and test reactors, fuel reprocessing plants (FRPs) (currently, use of FRPs in the commercial sector is not being considered), small mixed oxide fuel fabrication plants, uranium hexafluoride conversion plants, uranium fuel fabrication plants, independent spent fuel storage installations, and non-fuel-cycle facilities for handling byproduct, source and special nuclear materials. Excluded here from consideration for regulation change, are decommissioning of low-level waste burial facilities, high-level waste repositories, and uranium mill and mill tailings piles, which are covered in separate rulemaking activities, and decommissioning of uranium mines which are not under NRC jurisdiction.

Decommissioning has many positive environmental impacts such as the return of possibly valuable land to the public domain and the elimination of potential problems associated with increased numbers of radioactively contaminated facilities with a minimal use of resources. Major adverse impacts are shown to be routine occupational radiation doses and the commitment of nominally small amounts of land to radioactive waste disposal. Other impacts, including public radiation doses, are minor. Mitigation of potential health, safety, and environmental impacts requires more specific and detailed regulatory guidance than is currently available. Recommendations are made as to regulatory decommissioning particulars including such aspects as decommissioning alternatives, appropriate preliminary planning requirements at the time of commissioning, final planning requirements prior to termination of facility operations, assurance of funding for decommissioning, environmental review requirements,

OVERVIEW

At the end of a commercial nuclear facility's useful life, termination of its license by the Nuclear Regulatory Commission (NRC) is a desired objective. Such termination requires that the facility be decommissioned. Decommissioning means the removal of a nuclear facility safely from service and reduction of residual radioactivity to a level that permits release of the property for unrestricted use and termination of the license. It is the objective of NRC regulatory activities in protecting public health and safety to provide to the applicant or licensee appropriate regulations and guidance to accomplish nuclear facility decommissioning.

Although decommissioning is not an imminent health and safety problem, the nuclear industry is maturing. Nuclear facilities have been operating for a number of years, and the number and complexity of facilities that will require decommissioning is expected to increase in the near future. Accordingly, the NRC is reevaluating its regulatory requirements concerning decommissioning. This final generic environmental impact statement is part of this reevaluation.

PAST ACTIVITIES

In support of this reevaluation, a data base on the technology, safety, and cost of decommissioning various nuclear facilities and on other matters related to decommissioning, including financial assurance, is being completed for the NRC by Battelle Pacific Northwest Laboratory (PNL), by Oak Ridge National Laboratory and by other contractors. Based on this data base and on input from other State and Federal government agencies and the public, NRC has modified and amplified its policy considerations and data base requirements in a manner responsive to comments received. Another area addressed is the generic applicability of the data base for specific facility types. This has been addressed through expansion of the PNL facility reports to include sensitivity analyses for a variety of parameters potentially affecting safety and cost considerations. A draft generic environmental impact statement was issued in January, 1981 and comments received have been considered in the development of this final statement. On February 11, 1985, the NRC published a notice of proposed rulemaking on Decommissioning Criteria for Nuclear Facilities (50 FR 5600). The proposed amendments covered a number of topics related to decommissioning that would be applicable to 10 CFR Parts 30, 40, 50, 51, 70, and 72 applicants and licensees. These topics included decommissioning alternatives, planning, assurance of funds for decommissioning, environmental review requirements, and residual radioactivity.

SCOPE OF THE EIS

Regulatory changes are being considered for both fuel cycle and non-fuel-cycle nuclear facilities. The fuel cycle facilities are pressurized (PWR) and boiling water (BWR) light water reactors (LWRs) for both single and multiple reactor sites, research and test reactors, fuel reprocessing plants (FRPs) (currently, use of FRPs in the commercial sector is not being considered), small mixed oxide (MOX) fuel fabrication plants, uranium fuel fabrication plants (U-fab), uranium hexafluoride conversion plants (UF_6), and independent spent fuel storage installations (ISFSI). Under non-fuel-cycle facilities,

consideration is given to major types such as radiopharmaceutical or industrial radioisotope supplier facilities, various research radioisotope laboratories, and rare metal ore processing plants where uranium and thorium are concentrated in the tailings.

This EIS addresses only those issues involved in the activities carried out at the end of a nuclear facility's useful life which permit the facility to be removed safely from service and the property to be released for unrestricted use. It does not address the considerations involved in extending the life of a nuclear facility. If a licensee makes an application for extending a facility license, an application for license renewal or amendment or for a new license would be submitted and reviewed according to appropriate existing regulations. This is not considered to be decommissioning and therefore is outside the scope of this EIS.

High-level waste repositories, low-level waste burial facilities, and uranium mills and their associated mill tailings piles are covered in separate rulemakings and are not included here. The first two items are covered in Title 10 of the Code of Federal Regulations (10 CFR) Parts 60 and 61. The last item is covered in amendments to 10 CFR Part 40.

REGULATORY OBJECTIVE

It is the responsibility of the NRC to ensure, through regulations and other guidance, that appropriate procedures are followed in decommissioning to protect the health and safety of the public. Present regulatory requirements and guidance cover the requirements and criteria for decommissioning in a limited way and are not adequate to regulate decommissioning actions effectively. Areas needing further criteria include decommissioning alternatives, financial assurance, planning and residual radioactivity levels as discussed below:

Decommissioning Alternatives. It is the responsibility of the NRC, in protecting public health and safety, to ensure that after a nuclear facility ceases operation its license is terminated in a timely manner. License termination requires decommissioning. Analysis of the technical data base, establishes that decommissioning can be accomplished and the facility released for unrestricted use shortly after cessation of operations or, in certain situations for certain facilities, delayed and completed after a period of storage. These situations would include considerations where the potential exists for occupational exposure and waste volume reduction, resulting from radioactive decay, or the inability to dispose of waste due to lack of disposal capacity, or other site specific factors which may affect safety. Completing decommissioning and releasing the site for unrestricted use eliminates the potential problems that may result from an increasing number of sites contaminated with radioactive material, as well as eliminating potential health, safety, regulatory, and economic problems associated with maintaining the nuclear facility.

Based on the technical data base, it appears that completing decommissioning shortly after cessation of facility operations or delaying completion of decommissioning for a 30 to 50 year period are reasonable options for decommissioning light water power reactors. Delay beyond that period may be acceptable if there is an inability to dispose of waste due to lack of disposal capacity or if there are site specific factors affecting safety such as if the safety of an adjacent reactor might be affected by dismantlement procedures.

For research and test reactors and for nuclear facilities licensed under 10 CFR Parts 30, 40, 70, and 72, occupational doses would be in most cases much less significant than power reactors. Thus, completing decommissioning shortly after cessation of operations is considered the most reasonable option. Delaying completion of decommissioning to allow short lived nuclides to decay may be justified in some cases, however, any extended delay would rarely be justifiable.

Financial Assurance. Consistent with the regulatory objective of decommissioning as described above, reasonable assurance is required from the nuclear facility licensee that adequate funds are available to decommission the facility. The funding mechanisms considered reasonable for providing the necessary assurance include prepayment of funds into a segregated account, insurance, surety bonds, letters of credit, and certain other guarantee methods, and a sinking fund deposited into a segregated account.

Planning. Planning for decommissioning is a critical item for ensuring that the decommissioning activities can be accomplished in a safe and timely manner. Development of detailed plans at the application stage is not possible because many factors (e.g., technology, regulatory requirements, economics) will change before the license period ends. Thus, most of the planning for the actual decommissioning will occur near final shutdown. However, a certain amount of preliminary planning should be done at the application stage.

Information on decommissioning funding provisions must be submitted with an application for a license for a nuclear facility. This information should include the method of assuring funds for decommissioning (as discussed above under Financial Assurance) and an indication of the amount being set aside. Provisions should also be made to adjust cost levels and associated funding levels over the life of the facility.

Facilitation of decommissioning in the design of a facility or during its operation can be beneficial in reducing operational exposures and waste volumes requiring disposal at the time of decommissioning. Although many aspects of facilitation can be covered under existing regulations, specific requirements that records of relevant operational and design information important to decommissioning be maintained should be added.

A final detailed decommissioning plan is required for review and approval by the NRC prior to cessation of facility operation or shortly thereafter. Besides the description of the decommissioning alternative which will be used, the final plan should include a description of the plans to ensure occupational and public safety and to protect the environment during decommissioning; a description of the final radiation survey to ensure that remaining residual radioactivity is within levels permitted for releasing the property for unrestricted use; an updated cost estimate; and for certain facilities as appropriate a description of quality assurance and safeguards provisions. The plan should include an estimate of the cost required to accomplish the decommissioning.

Residual Radioactivity Levels. The selection of an acceptable level is outside the scope of rulemaking supported by this EIS. The Commission is participating in an EPA organized interagency working group which is developing Federal guidance on acceptable residual radioactivity for unrestricted use. Proposed Federal guidance is anticipated to be published by EPA. NRC is planning to

implement this guidance through rulemaking as soon as possible, as well as by issuing regulatory guides and standard review plan sections. Currently, criteria for residual contamination levels do exist and research and test reactors are being decommissioned using present guidance contained in Regulatory Guide 1.86 for surface contamination plus 5 μr/hr above background measured at 1 meter from the surface for direct radiation. The cost estimate for decommissioning can be based on current criteria and guidance regarding residual radioactivity levels for unrestricted use. The information in the studies performed as part of the reevaluation on decommissioning have indicated that in any reasonable range of residual radioactivity limits, the cost of decommissioning is relatively insensitive to the radioactivity level and use of cost data based on current criteria should provide a reasonable estimate. Even in situations where the residual radioactivity level might have an effect on decommissioning cost, by use of update provisions in the rulemaking, it is expected that the decommissioning fund available at the end of facility life will approximate closely the actual cost of decommissioning.

ENVIRONMENTAL IMPACT STATEMENT

Generally, the major environmental impact from decommissioning, especially for power reactors, occurs when the decision is made to operate the reactor. Provided decommissioning rules are in place and based on the conclusions of Chapters 4 and 5 regarding impacts from reactor decommissioning alternatives, it is not expected that any significant environmental impacts will result from decommissioning. Therefore current 10 CFR Part 51 needs to be amended to delete the manditory EIS requirement for decommissioning of power reactors. An EIS may still be needed but this should be based on site specific factors. Consequently a licensee should submit a supplemental environmental report and safety analysis and, based on these submittals, the NRC should consider preparation and issuance of an environmental assessment and a finding of no environmental impact. This is expected to be reasonable for most situations.

It is imperative that decommissioning rule amendments in 10 CFR Parts 30, 40, 50, 51, 70, and 72 be issued at this time because it is important to establish financial assurance provisions, as well as other decommissioning planning provisions, as soon as possible so that funds will be available to carry out decommissioning in a manner which protects public health and safety. Based on this need for the decommissioning provisions currently existing as well as those contained in the proposed rule amendments, the Commission believes that the rule can and should be issued now.

CONCLUSIONS ON DECOMMISSIONING IMPACTS

Consideration of the decommissioning data base including comments on the Draft Generic Environmental Statement and on the proposed rule and of the need for regulatory activity has led to the following conclusions in the Final Generic Environmental Impact Statement:

(1) The technology for decommissioning nuclear facilities is well in hand and, while technical improvements in decommissioning techniques are to be expected, decommissioning at the present time can be performed safely and at reasonable cost. Radiation dose to the public due to decommissioning activities should be very small and be primarily due to transportation of

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1 INTRODUCTION

Commercial nuclear facilities that come under the Nuclear Regulatory Commission's (NRC) regulatory authority include those dealing with fuel cycle and non-fuel-cycle operation. The generation of electric power from steam supplied by nuclear reactors requires a series of processes collectively known as the nuclear fuel cycle. This cycle begins with the mining and milling of uranium ore, includes the operation of power reactors, and ends with the disposition of radioactive wastes. Each step in the cycle requires the handling of radioactive materials, which are specifically designated as source materials, byproduct materials, or special nuclear materials. Non-fuel-cycle facilities can also use byproduct, source, and special nuclear materials. Non-fuel-cycle facilities include those involved in academic, pharmaceutical and industrial radioisotopic use and in rare metal ore processing. The handling of these materials and the processes involved have given rise to several issues of fundamental importance to the American public. These issues include the safe operation of all steps in the nuclear fuel cycle and of other nuclear facilities, especially the safe operation of power reactors; the safe disposition of radioactive wastes; and the safe decommissioning of all nuclear facilities. The first two issues have received much attention from Congress and from federal regulatory agencies, beginning in 1954 with the passage of the Atomic Energy Act. The third issue, decommissioning, is now receiving an increasing amount of attention because the nuclear field is maturing, in that nuclear facilities have been operating for a number of years, and the number and complexity of facilities that will require decommissioning is expected to increase in the future. It is this third issue which is the subject of this document.

1.1 Purpose of EIS

The purpose of this environmental impact statement (EIS) is to assist the Nuclear Regulatory Commission (NRC) in developing policies and in promulgating amended regulations with respect to the decommissioning of licensed nuclear facilities. It is prepared pursuant to the requirements of the National Environmental Policy Act (NEPA). The decommissioning of uranium mills and mill tailings, (this includes all facilities associated with extracting uranium from areas, such as in situs, heap leach, and milling facilities) low-level waste burial facilities and high-level waste repositories has been treated in 10 CFR Parts 40, 60 and 61. In addition, also excluded from this action are uranium mines which come under the jurisdiction of the states and other Federal agencies. The generic analyses of this EIS are applicable to specific facilities based on the decommissioning information base studies which included sensitivity analyses of such parameters as the size of the facility, contamination level, waste disposal costs, labor costs, etc. (See References of Section 1)

1.1.1 NEPA Requirements

Section 102(1) of the National Environmental Policy Act (42 U.S.C. 4321 et seq.) requires that "the policies, regulations, and public laws of the United States shall be interpreted and administered in accordance with the policies set forth in this Act." Section 102(2)(C) requires all agencies of the Federal

Government to "include in every recommendation or report on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment, a detailed statement by the responsible official on:

(i) the environmental impact of the proposed action,

(ii) any adverse environmental effects which cannot be avoided should the proposal be implemented,

(iii) alternatives to the proposed action,

(iv) the relationship between local short-term uses of man's environment and the maintenance and enhancement of long-term productivity, and

(v) any irreversible and irretrievable commitments of resources which would be involved in the proposed action should it be implemented."

1.2 Organization of the EIS

The first three sections of this EIS contain material common to all of the facilities discussed in the statement. Regulatory matters are discussed in Section 1. Section 2 discusses in a generic manner the following: nuclear facilities; decommissioning alternatives; acceptable residual radioactivity levels for permitting release of the site for unrestricted use; financial assurance that sufficient funds are available for decommissioning; the management of radioactive wastes; and safeguards. Facility sites (i.e., the affected environment) are discussed generically in Section 3. Reactor facilities are discussed in Sections 4 through 8. Fuel cycle facilities are discussed in Sections 9 through 13 and non-fuel-cycle facilities in Section 14. These sections include descriptions of each facility, discussions of decommissioning alternatives, and summaries of radiation exposures and decommissioning costs. Other environmental consequences are also discussed. Regulatory policy considerations are discussed in Section 15.

It is intended in this report to provide a document sufficient in detail to be useful to the NRC in establishing policies and in promulgating amended regulations, yet not so lengthy or detailed as to be overwhelming to the general public and to others who have a valid interest in the subject. Detailed reports have been prepared which constitute information bases on the technology, safety and costs of decommissioning of the nuclear facilities discussed in this report.[1-10] These facilities are pressurized water reactors, boiling water reactors, multiple reactor power stations, research and test reactors, fuel reprocessing plants, small mixed oxide fuel fabrication plants, uranium hexafluoride conversion plants, uranium fuel fabrication plants, independent spent fuel storage installations, and non-fuelcycle materials facilities. Many of those reports have been available for critical comment for some time, have been found to be useful as a data base, and have been used in preparation of decommissioning studies. The decommissioning of uranium mills and tailings piles is discussed in a separate EIS.[11] The decommissioning of low-level waste burial facilities is also discussed in a separate EIS.[12]

This EIS represents a compendium of what would otherwise have been many separate EIS's on the nuclear facilities considered in this report. To make the

report more useful to the user, the separate facility sections (Section 4 through 14) were kept as self-contained as possible, so that a user interested in a particular facility type need primarily read only that section, as well as the introduction, the section on generic issues and the section on policy. Such an approach causes some unavoidable redundancy in presentation of information contained in the various facility sections. In addition, an overview of this report is presented to enable a user to gain a perspective of the objectives and conclusions reached in this report.

1.3 Purpose of Decommissioning

The purpose of decommissioning nuclear facilities is to take the facility safely from service and to reduce residual radioactivity to a level that permits release of the property for unrestricted use and termination of license. Alternative methods of accomplishing this purpose, and the environmental impacts of each alternative are discussed in this EIS.

1.4 Responsibility for Decommissioning

The responsibility for decommissioning a commercial nuclear facility belongs to the licensee. Regulatory and policy guidance for decommissioning is the responsibility of the NRC and is implemented either by the NRC or Agreement State as applicable.

1.4.1 Existing Criteria and Regulations for Decommissioning

Statutory authority for the regulation of activities related to the commercial nuclear fuel cycle is contained in the Atomic Energy Act of 1954 (42 U.S.C. 2011 et seq.) and the Energy Reorganization Act of 1974 (42 U.S.C. 5841 et seq.) and in subsequent amendments. Pursuant to these acts, the NRC has promulgated regulations which appear in Title 10 of the Code of Federal Regulations. The NRC has also published Regulatory Guides for the purpose of assisting applicants and licensees in carrying out their regulatory obligations.

Present regulations specifically pertaining to decommissioning are contained in 10 CFR Parts 40, 61, and 72 and in Section 50.33(f), Section 50.82, and Appendix F of 10 CFR Part 50. General guidance is contained in NRC Regulatory Guides 1.86 and 3.5 (Rev. 1) and in NRC staff guidelines.

1.4.2 Current Rulemaking Activities

The NRC is currently developing an explicit overall policy for decommissioning commercial nuclear facilities and amending its regulations in 10 CFR Chapter I to include more specific decommissioning guidance for production and utilization facility licensees and byproduct, source, and special nuclear material licensees.[13] On February 11, 1985, the NRC published a notice of proposed rulemaking on Decommissioning Criteria for Nuclear Facilities (50 FR 5600). The proposed amendments covered a number of topics related to decommissioning that would be applicable to 10 CFR Parts 30, 40, 50, 70, and 72 applicants and licensees. These topics included decommissioning alternatives, planning, assurance of funds for decommissioning, environmental review requirements, and residual radioactivity.

1.5 History, Background, and Experience With Decommissioning

Facilities identified with the portion of the nuclear fuel cycle between mining and reactor operation, uranium hexafluoride conversion plants and uranium fuel fabrication plants, call for relatively routine decommissioning procedures. These facilities usually contain low-level radioactivity which is well confined to the facility. Mixed oxide fuel fabrication plants involve plutonium and thus call for special procedures. Pressurized water reactors, boiling water reactors, fuel reprocessing plants, and spent fuel storage facilities contain high levels of radioactivity that require special precautions and procedures. The differences among research and test reactors that have a variety of functions and the complexity of non-fuel-cycle facilities that handle byproduct, source, or special nuclear materials depend on the activities carried out and the materials handled. However, their problems in decommissioning these facilities are more from the great number and variety, than in any technical difficulties.

Since 1960, five licensed power reactors, four demonstration reactors, six licensed test reactors, one licensed ship reactor, and 52 licensed research reactors and critical facilities have been or are being decommissioned by the methods discussed in this EIS. Forty-two research reactors and critical facilities have been dismantled. Only one power reactor, the Elk River demonstration reactor, has been completely dismantled. Three other demonstration power reactors of small size have been entombed. The decommissioning status of the more important reactors is listed in Table 1.5-1. Some military reactors are included, while licensed research reactors and critical facilities have been omitted.

Decommissioning experience with some of the specific types of facilities is limited, but a broad base of experience with various facilities exists which is generally relevant to the decommissioning of any type of nuclear facility. A sampling of non-reactor facilities which have been decommissioned is presented in Table 1.5-2.

2 GENERIC NUCLEAR FACILITY DECOMMISSIONING CONSIDERATIONS

In this section consideration is given to generic items required for implementing a decommissioning program for the facilities considered in this EIS. First, for an overview, a brief discussion is presented of the nuclear fuel cycle for light-water-reactors. Research and test reactors and non-fuel-cycle nuclear facilities are also briefly discussed. Consideration is then given to:

(1) decommissioning alternatives and their advantages and disadvantages,

(2) acceptable residual radioactivity levels for permitting release of a decommissioned nuclear facility for unrestricted access,

(3) assurance that funds to pay for decommissioning will be available,

(4) waste management for radioactive waste needing to be disposed of during nuclear facility decommissioning, and

(5) safeguarding requirements during decommissioning.

2.1 Nuclear Facilities Operational Description

2.1.1 The Nuclear Fuel Cycle

A nuclear power plant is a facility designed to generate electricity by utilizing the heat produced by controlled nuclear fission of uranium and plutonium. This is the desired production step in the fuel cycle. It is preceded by several steps in the fuel cycle in which uranium ore is processed into fuel elements, and is followed by several steps in which fuel removed from the reactor is stored and then either reprocessed to recover usable fuel or disposed of in some manner. The basic steps in the nuclear fuel cycle are shown in Figure 2.1-1. Each box in the diagram represents a separate facility and each arrow represents the transportation of the product between facilities. Spent fuel is being stored at the reactor sites pending eventual disposal at spent fuel storage facilities or high-level waste repositories.

The steps in Figure 2.1-1 for the typical fuel cycle for power plants are described more fully below.

Milling

The uranium ores that are mined and milled in the United States are sedimentary deposits in which the uranium occurs as a coating on sand grains. Small quantities of radium and thorium are also found in the ore. The uranium content is only about 1 to 3 kg per tonne (2 to 6 lb per ton). The milling process dissolves the uranium and separates it from the sand. This involves crushing and grinding the ore, dissolving the uranium by acid or alkaline leach, and precipitating a semi-refined product, called yellowcake. The tailings from this process are mostly sand, but they also include the original quantities of radium, thorium, and other decay products that do not extract

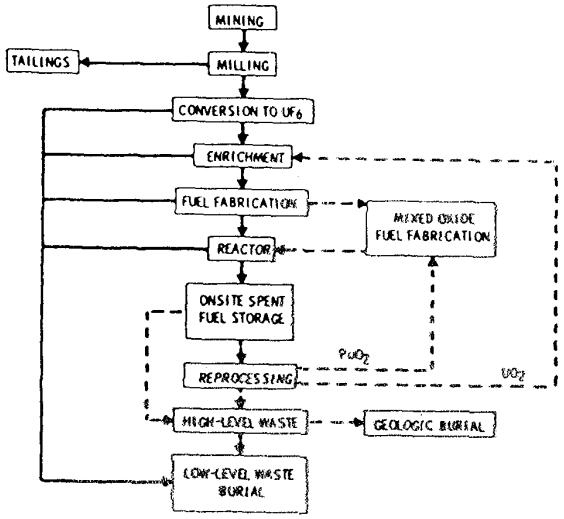

Figure 2.1-1 Diagram of the steps in the nuclear fuel cycle

with the uranium. The tailings are carried as a slurry to impoundment areas where the water is allowed to evaporate. The tailings are then stabilized to reduce future potential contamination problems.

Conversion

The yellowcake is shipped to a conversion plant where it is converted to UF_6 by one of two processes. One is the "dry" or hydrofluor process in which the yellowcake goes through a series of reduction, hydrofluorination, and fluorination steps in fluidized bed reactors. The other is a "wet" process in which the yellowcake is first processed to produce a high-purity uranium dioxide feed that undergoes reduction, hydrofluorination, and fluorination.

Enrichment

The UF_6 produced by the conversion process contains about 0.7% ^{235}U, which must be increased to 2 to 4% prior to fabrication into LWR fuel assemblies. Enrichment is accomplished by a gaseous diffusion process in which $^{235}UF_6$ molecules pass more readily through a porous membrane than do $^{238}UF_6$ molecules, thus producing a product stream that is enriched in $^{235}UF_6$. This process is repeated through many such stages until the desired degree of enrichment is attained. The enriched UF_6 is then shipped to a fuel fabrication plant.

Fuel Fabrication

In the preparation of LWR fuel, the enriched UF_6 first undergoes chemical treatment to convert it to UO_2. The UO_2 is mechanically and thermally treated to produce high-density ceramic fuel pellets that are placed in metal fuel tubes. These tubes or rods are then clustered into fuel assemblies for reactor cores.

Reactors

A light water reactor (LWR) as used in a power plant utilizes the heat produced by controlled nuclear fission within the fuel assemblies in the reactor core to heat water and generate steam which drives a turbine-generator. There are two basic LWR types: the pressurized water reactor (PWR) and the boiling water reactor (BWR). In a PWR the water in the reactor core is kept under pressure to allow heat build-up without boiling. This heated water is circulated through a heat exchanger where water in a second circulating system is converted to steam to drive the turbines. In a BWR the water in the reactor core is allowed to boil, directly producing the steam to drive the turbines.

Spent Fuel Storage Facilities

The partially depleted LWR spent fuel assemblies are removed from the reactor and stored in spent fuel pools at the reactor for a minimum of 90 days. This cooling period allows the short-lived radionuclides to decay and reduce the radioactivity and thermal heat emission of the fuel assemblies.

Spent fuel is currently being stored at reactor spent fuel pools for extended time periods as plans for further disposition of the spent fuel are being developed. Storage of spent fuel at away-from-reactor independent spent fuel storage installations (ISFSI) is being considered as an interim measure. One

ISFSI design is similar to that of the reactor storage pools except that the storage capacity is significantly greater. An alternative ISFSI design is to store the spent fuel in a dry storage environment such as an air-cooled vault.

Fuel Reprocessing

LWR spent fuel assemblies can be chemically reprocessed to separate the remaining uranium and the generated plutonium from the radioactive wastes produced during reactor operation. The chemical separation is accomplished by chopping the fuel rods into short sections, dissolving the pellets with nitric acid, extracting uranium and plutonium nitrates from the fission products, and then separating the uranium from the plutonium. The uranyl nitrate is converted to UF_6 and the plutonium nitrate is oxidized to plutonium dioxide. Both can then be inserted into the fuel cycle for reuse. At the present time no commercial spent fuel is being reprocessed in the United States.

Mixed Oxide Fuel Fabrication

A mixed oxide fuel fabrication plant produces fuel elements that contain a mixture of UO_2 and PuO_2. For example, UO_2 and PuO_2 powders are mixed and the mixture is formed into pellets by mechanical and thermal treatment. These pellets are sealed in metal cladding to form fuel elements. Only small mixed oxide plants are currently in use commercially and are used to fabricate experimental fuel elements.

Low-Level Waste Burial Facilities

Low-Level radioactive wastes which do not contain transuranic elements above certain concentrations are disposed of in shallow-land burial facilities. These kinds of materials may be generated at reactors or at any of the facilities where fuel is processed, and consist of contaminated trash, filters, and equipment. These wastes are placed in boxes or drums to facilitate handling and are buried at sites that are monitored and are restricted from public access.

High-Level Waste Repositories

High-level wastes are either intact fuel assemblies that are being discarded after serving their useful life in a reactor core (spent fuel) or certain fission product and actinide wastes generated during fuel reprocessing. High-level waste burial at deep geologic repositories is currently under consideration. There are currently no facilities of this type.

2.1.2 Research and Test Reactors

A research reactor is defined in 10 CFR 170.3(h) as a nuclear reactor licensed for operation at a thermal power level of 10 megawatts or less, and which is not a testing facility. A testing facility (i.e., a test reactor) is defined in 10 CFR 50.2 as a nuclear reactor licensed for operation at: (1) a thermal power level in excess of 10 megawatts, or (2) a thermal power level in excess of 1 megawatt if the reactor is to contain: a circulating loop through the core in which the applicant proposes to conduct fuel experiments, or a liquid fuel loading, or an experimental facility in the core in excess of 16 square inches in cross-section. There are 84 nonpower research and test (R&T) reactors in the U.S. that are licensed by the NRC. Of these 76 are research reactors, and

8 are test reactors. The level of activity of these facilities ranges from no longer operational, to occasional use, to intermittent use, to steady and scheduled use.

2.1.3 Non-Fuel-Cycle Nuclear Facilities

Non-fuel-cycle facilities are those facilities which handle by-product, source and/or special nuclear materials, but which are not involved in the production of power as outlined in Figure 2.1-1. Non-fuel-cycle facilities must be licensed by the NRC. Precise definitions and licensing requirements for the materials listed above are published in 10 CFR Parts 30, 40, and 70, respectively. Broadly speaking, source materials consist of uranium and thorium, special nuclear materials consist of plutonium or enriched uranium, and byproduct materials consist of materials made radioactive by special nuclear material. These facilities include a wide range of applications in industry, medicine and research such as manufacture of packaged products containing small sealed sources and of radiochemicals, research and development institutions, and processors of ores in which the tailings contain licensable quantities of radionuclides.

2.2 Facilities Considered in EIS

The facilities considered in this EIS are: (1) pressurized water reactors, (2) boiling water reactors, (3) multiple reactor stations, (4) research and test reactors, (5) fuel reprocessing plants, (6) small mixed oxide fuel fabrication plants, (7) uranium hexafluoride conversion plants, 8) uranium fuel fabrication plants, (9) independent spent fuel storage installations, and (10) non-fuel-cycle nuclear facilities. The facilities not considered include uranium mills and mill tailings, low-level waste burial facilities and high-level waste repositories because they are covered by separate rulemaking; and uranium mines and the existing government owned uranium enrichment plants because they are not under NRC jurisdiction.

2.3 Definition of Decommissioning

Decommissioning means to remove a nuclear facility safely from service and to reduce residual radioactivity to a level that permits release of the property for unrestricted use and termination of the license. Decommissioning activities do not include the removal and disposal of spent fuel which is considered to be an operational activity or the removal and disposal of nonradioactive structures and materials beyond that necessary to terminate the NRC license. Disposal of nonradioactive hazardous waste not necessary for NRC license termination is not covered in detail by this EIS but would be treated by other agencies having responsibility over these wastes as appropriate.

2.4 Decommissioning Alternatives

Once a nuclear facility has reached the end of its useful life, it must be decommissioned according to the definition contained in Section 2.3. Several alternatives are possible, although not all may be satisfactory for all nuclear facilities. These alternatives are: no action, DECON, SAFSTOR, and ENTOMB. The terms DECON, SAFSTOR, and ENTOMB are relatively new in use. In the past, the nomenclature for describing these alternatives has not been consistent. Different documents have often used different terminology when referring to the same decommissioning alternative, thus causing some confusion. In the interest

of ending the confusion, this section lists the following definitions of the major decommissioning alternatives and the following pseudoacronyms to clearly delineate each alternative:

DECON is the alternative in which the equipment, structures, and portions of the facility and site containing radioactive contaminants are removed or decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations.

SAFSTOR is the alternative in which the nuclear facility is placed and maintained in a condition that allows the nuclear facility to be safely stored and subsequently decontaminated (deferred decontamination) to levels that permit release for unrestricted use.

ENTOMB is the alternative in which radioactive contaminants are encased in a structurally long-lived material, such as concrete; the entombed structure is appropriately maintained and continued surveillance is carried out until the radioactivity decays to a level permitting release of the property for unrestricted use.

Table 2.4-1 presents a summary of the various activities that will be in effect during DECON, SAFSTOR and ENTOMB.

Conversion to a new or modified use is also considered. Conversion, however, is not considered to be a decommissioning alternative whether the new use involves radioactivity or not. If the intended new use involved radioactive material and, thus was under NRC licensing authority, an application for license renewal or amendment or for a new license would be submitted and reviewed according to appropriate existing regulations. If the intended new use does not involve radioactive materials, i.e., unrestricted public use, then such new use would be contingent on prior decommissioning and termination of license. As such, it would have to use one of the decommissioning alternatives indicated above, namely DECON, SAFSTOR, or ENTOMB. In this case, the new use except as it affects the decommissioning alternative chosen. For these reasons, conversion to a new or modified facility is not considered further in this EIS.

2.4.1 No action

The objective of decommissioning is to restore a radioactive facility to a condition such that there is no unreasonable risk from the decommissioned facility to the public health and safety. In order to ensure that at the end of its life the risk from a facility is within acceptable bounds, some action is required, even if it is as minimal as making a terminal radiation survey to verify the radioactivity levels and notifying the NRC of the results of the survey. Thus, independent of the type of facility and its level of contamination, No Action, implying that a licensee would simply abandon or leave a facility after ceasing operations, is not a viable decommissioning alternative. Therefore, because no action is not considered viable for any facility discussed in this EIS, this alternative is not considered further in this report.

2.4.2 DECON

DECON is the alternative in which the equipment, structures, and portions of a facility and site containing radioactive contaminants are removed or

Table 2.4-1 Summary of the elements of the decommissioning alternatives

Elements[a]	Facility Status	Comments, Facility/Site Use
Decontamination [to levels permitting unrestricted use of the facility]	Equipment - removed if radioactive Continuing Care Staff - none Security - none Environmental Monitoring - none Radioactivity - removed Surveillance - none Structures - removal optional	Facility - Unrestricted use reaching permissible levels Site - Unrestricted use after reaching permissible levels
Safe Storage Custodial (Layaway)	Equipment - some operating Continuing Care Staff - some required Security - continuous Environmental Monitoring - continuous Radioactivity - confined Surveillance - continuous Structures - intact	Safe storage alone is not an acceptable decommissioning mode; it must be followed by decontamination to unrestricted use. Facility - Nuclear Only Site - Nuclear Only
Passive	Equipment - none operating Continuing Care Staff - optional (onsite) - routine inspections Security - remote alarms Environmental Monitoring - routine periodic Radioactivity - immobilized/sometimes sealed Surveillance - periodic Structures - intact	Facility - Nuclear Only Site - Conditional Non-nuclear

Table 2.4-1 (Continued)

Elements[a]	Facility Status	Comments, Facility/Site Use
Hardened	Equipment - none operating Continuing Care Staff - none on site *Security - hardened barriers, fencing and posting* Environmental Monitoring - infrequent Radioactivity - hardened sealing Surveillance - infrequent Structures - partial removal optional	Facility - Conditional Non-nuclear Site - Conditional Non-nuclear
Entombment	Equipment - some removed, the rest encased in concrete Site - unrestricted Continuing Care Staff - none Security - hardened barriers Environmental Monitoring - infrequent Radioactivity - encased in concrete Surveillance - infrequent Structures - intact	Facility - Unusable for an extended time period Site - Unrestricted use

[a]Elements are the specific activities involved in each of the decommissioning alternatives, e.g., SAFSTOR is made up of the following elements: preparation for safe storage, safe storage and decontamination.

decontaminated to a level that permits the property to be released for unrestricted use shortly after cessation of operations. DECON is the only one of the decommissioning alternatives presented here which leads to termination of the facility license and release of the facility and site for unrestricted use shortly after cessation of facility operations. DECON is estimated to take from fairly short time periods for small facilities to up to approximately 6 years for a large LWR.

Because all of the DECON work is completed within a few months or years following shutdown, personnel radiation exposures are generally higher than for other decommissioning alternatives which spread the decommissioning work over longer time periods thus allowing for radioactive decay. Similarly, larger commitments of money and waste disposal site space are also required for DECON in a relatively short time frame compared to the other alternatives.

Thus, the primary advantage of DECON, which is terminating the facility license and making the facility and site available for some other beneficial use, is accomplished at the expense of larger initial commitments of money, personnel radiation exposure, and waste disposal site space than for the other alternatives. Other advantages of DECON include the availability of a work force highly knowledgeable about the facility and the elimination of the need for long-term security, maintenance and surveillance of the facility which would be required for the other decommissioning alternatives.

In DECON, nonradioactive equipment and structures need not be torn down or removed as part of a decontamination procedure for termination of the NRC license and release for unrestricted use. Once the radioactive facility structures are decontaminated to radioactivity levels permitting unrestricted use of the facility, they may either be put to some other use or demolished at the owner's option.

2.4.3 SAFSTOR

SASTOR is the alternative in which the nuclear facility is placed (preparation for safe storage) and maintained in a condition that allows the nuclear facility to be safely stored (safe storage) and subsequently decontaminated to levels that permit release for unrestricted use (deferred contamination). SAFSTOR consists of a short period of preparation for safe storage (up to 2 years after final reactor shutdown), a variable safe storage period of continuing care consisting of security, surveillance, and maintenance (up to 60 years after final shutdown depending on the type of facility), and including a short period of deferred decontamination. Several subcategories of SAFSTOR are possible:

1. Custodial SAFSTOR requires a minimum cleanup and decontamination effort initially, followed by a period of continuing care with the active protection systems (principally the ventilation system) kept in service throughout the storage period. Full-time onsite surveillance by operating and security forces is required to carry out radiation monitoring, to maintain the equipment, and to prevent accidental or deliberate intrusion into the facility and the subsequent exposure to radiation or the dispersal of radioactivity beyond the confines of the facility.

2. Passive SAFSTOR requires a more comprehensive cleanup and decontamination effort initially, sufficient to permit deactivation of the active

protective (ventilation) system during the continuing care period. The structures are strongly secured and electronic surveillance is provided to detect accidental or deliberate intrusion. Periodic monitoring and maintenance of the integrity of the structures is required.

3. Hardened SAFSTOR requires comprehensive cleanup and decontamination and the construction of barriers around areas containing significant quantities of radioactivity. These barriers are of sufficient strength to make accidental intrusion impossible and deliberate intrusion extremely difficult. Surveillance requirements are limited to detection of attack upon the barriers, to maintenance of the integrity of the structures, and to infrequent monitoring.

All categories of safe storage require some positive action at the conclusion of the period of continuing care to release the property for unrestricted use and terminate the license for radioactive materials. Depending on the nature of the nuclear facility and its operating history, the necessary action can range from a radiation survey that shows that the radioactivity has decayed and the property is releasable, to dismantlement and removal of residual radioactive materials. These latter actions, whatever their scale, are generically identified as deferred decontamination.

SAFSTOR is used as a means to satisfy the requirements for protection of the public while minimizing the initial commitments of time, money, occupational radiation exposure, and waste disposal space. In addition, SAFSTOR may have some advantage where there are other operational nuclear facilities at the same site, and may also become necessary in other situations if there is a shortage of radioactive waste disposal space offsite. Modifications to the facilities are limited to those which ensure the security of the buildings against intruders, and to those required to ensure containment of radioactive or toxic material. It is not intended that the facilities will ever be reactivated. In highly contaminated facilities and/or facilities with large amounts of activation products, there is the potential for incurring larger occupational radiation exposures if complete decontamination is performed immediately after shutdown (DECON). However, as a result of radioactive decay of this contamination, reductions in personnel exposure and simplifications in the complexity of operations can be achieved by deferring major decontamination efforts for a number of years. Also, because many of the contamination and activation products present in the facility will have decayed to background levels after a lengthy storage period, the volume of material that must be packaged for disposal will be reduced.

The reduced initial effort (and cost) of the preparation of safe storage is tempered somewhat by the need for continuing surveillance and physical security to ensure the protection of the public. Electronic surveillance devices, which are presently available, could be in service fulltime, with offshift readouts in a local law enforcement office or private security agency. These devices which monitor for intruders, increases in radiation levels, and detection of fires will require periodic checks and maintenance.

Maintenance of the facility's structures and an ongoing program of environmental surveillance are also necessary. The duration of the storage and surveillance and dismantlement period can vary from a few years to up to 60 years depending on the type of facility. If SAFSTOR is used, the decision on the length of the safe storage period will be made by the facility owner, with the

approval of the NRC, based on consideration of factors including desirability of terminating the license, radiation dose and waste volume reductions, availability of waste disposal capacity, and other site specific factors affecting safety, such as presence of other nuclear facilities at the site. Similarly, the decision on the extent of decontamination during the period of preparation for safe storage, and the resultant subcategory of SAFSTOR to be used, depends upon safety considerations and the planned length of the storage and surveillance period. If for example, ^{60}Co is the controlling source of occupational exposure, a chemical decontamination campaign achieving a decontamination factor (DF) of 10 (i.e., radioactivity levels reduced to 1/10 of original) will result in approximately the same dose reduction as a decay period of 17 years.

At the end of the period of safe storage, several things will remain to be done before the facility can be released for unrestricted use. In most cases, radioactivity in some areas within the facility will be significantly above levels acceptable for unrestricted release of the facility, necessitating the removal, packaging and disposal of selected materials at a regulated disposal site. If the safe storage period is sufficiently long, radioactive materials in the facility may have decayed to levels low enough to permit the facility to be released for unrestricted use without additional decontamination. This would not apply in the case of a reactor, if the reactor had been operated long enough to produce significant amounts of the long-lived isotopes ^{59} Ni and ^{94}Nb.

Deferred decontamination, even for a major facility such as a LWR, is a relatively straight-forward disassembly job complicated by whatever radioactivity remains. Removal and transport of the materials containing the radioactivity to a disposal site are the principal tasks that must be completed. Further action following termination of the NRC license and release for unrestricted use, such as disassembly of the various non-radioactive systems and use or demolition of the buildings, would be at the owner's discretion.

A disadvantage of SAFSTOR is the potential lack of personnel familiar with the facility at the time of deferred decontamination. More time and training would be needed. One potential solution to this problem would be the establishment of companies specializing in the decommissioning of nuclear reactor power station and other nuclear facilities. Other disadvantages include the fact that the site is tied up in a non-useful purpose for extended time period, regulatory uncertainties in the future, and the continuing need for maintenance, security and surveillance.

2.4.4 ENTOMB

ENTOMB is the alternative in which radioactive contaminants are encased in a structurally long-lived material, such as concrete; the entombed structure is appropriately maintained and continued surveillance is carried out until the radioactivity decays to a level permitting release of the property for unrestricted use. ENTOMB is intended for use where the residual radioactivity will decay to levels permitting unrestricted release of the facility within reasonable time periods (i.e., within the time period of continued structural integrity of the entombing structure as well as confidence in the reliability of continued radioactivity containment and access restriction, perhaps the order of 100 years). However, a few radioactive isotopes found in fuel reprocessing plants, nuclear reactors, fuel storage facilities, and mixed oxide facilities have half-lives in excess of 100 years and the radioactivity will

not decay to levels permitting release of the facilities for unrestricted use within the foreseeable lifetime of any man-made structure. Thus, the basic requirement of continued structural integrity of the entombment cannot be ensured for these facilities, and ENTOMB would not be a viable alternative in these circumstances. On the other hand, if the entombing structure can be expected to last many half-lives of the most objectionable long-lived isotope, then ENTOMB becomes a viable alternative because of the reduced occupational and public exposure to radiation. However, even in these circumstances, one of the difficulties with ENTOMB for any complex structure such as a reactor is that the radioactive materials remaining in the entombed structure would need to be characterized well enough to be sure that they will have decayed to acceptable levels at the end of the surveillance period. If this cannot be done adequately, deferred decontamination would become necessary, which would make ENTOMB more difficult and costly than DECON or SAFSTOR. Some method would have to be provided to demonstrate that the entombed radioactivity will decay to levels permitting release of the property for unrestricted use within the order of 100 years, which would be difficult. ENTOMB does, of course, contribute to the problems associated with increased numbers of sites dedicated for very long periods to the containment of radioactive materials.

2.5 Residual Radioactivity Levels for Unrestricted Use of a Facility

Decommissioning requires reduction of the radioactivity remaining in the facility to residual levels that permit release of the facility for unrestricted use and NRC license termination.

The Commission is participating in an EPA organized interagency working group which is developing Federal guidance on acceptable residual radioactivity levels for unrestricted use. Proposed Federal guidance is anticipated to be published by EPA. NRC is planning to implement this guidance through rulemaking as soon as possible. The selection of an acceptable level is outside the scope of rulemaking supported by this EIS. Currently, criteria for residual contamination levels do exist and research and test reactors are being decommissioned using present guidance contained in Regulatory Guide 1.86[5] for surface contamination plus 5 μr/hr above background as measured at 1 meter direct radiation. The NRC provided such criteria in letters to Stanford University, dated 3/17/81 and 4/21/82 providing "Radiation criteria for release of the dismantled Stanford Research Reactor to unrestricted access." The cost estimate for decommissioning can be based on current criteria and guidance regarding residual radioactivity levels for unrestricted use. The information in the studies by Battelle Northwest Laboratory and Oak Ridge National Laboratory on decommissioning have indicated that in any reasonable range of residual radioactivity limits, the cost of decommissioning is relatively insensitive to the radioactivity level and use of cost data based on current criteria should provide a reasonable estimate.

For example, in ORNL studies[1,2] for a PWR, certification surveys at realistic dose values 10 and 25 mrem/year were considered. It was indicated that a survey for the 10 mrem/year value was considered to be well within technical capability and could be done for a cost of approximately $250,000 (i.e., less than about 0.6% of estimated PWR decommissioning costs); and a survey for the 25 mrem/year value is estimated to cost not much less than that for 10 mrem/year (about $225,000).

There should be no significant additional decontamination effort required as a result of the termination survey, perhaps only cleanup of a few hot spots indicated by the survey. This is because the extensive efforts required to decontaminate the highly contaminated facility to low radioactivity level will result in residual radioactivity levels well below the limits which permit unrestricted release of the facility. It is also the case because spot surveys will be carried out periodically during the decommissioning period so that at the time of the termination survey the licensee is confident that decontamination efforts have achieved the acceptable residual radioactivity levels in most instances. Thus, because there should not be significant additional decontamination necessary after completion of the termination survey, the major cost and effort expected for verifying the required residual radioactivity levels for unrestricted facility use should come from the certification survey. As indicated above for the PWR example, these survey costs are expected to be a small fraction of the total decommissioning cost, and thus the effort to certify that the facility is available for unrestricted use should not add significantly to the overall decommissioning cost.

In addition, cost-benefit considerations are involved in the evaluation of the extent of facility decontamination necessary to reduce radioactive contamination to levels considered acceptable for releasing the facility for unrestricted use. As is discussed by PNL in NUREG/CR-0130,[3] and in NUREG/CR-0278,[4] and as is also inherent in the reports prepared by PNL for the other nuclear facilities discussed in this EIS, the cost of decontamination of a facility and thus its decommissioning cost, is essentially independent of the level to which it must be decontaminated as long as that level is in the range of 10 to 25 mrem/yr to an exposed individual. This is because, as indicated above, it is expected that the extensive efforts required to decontaminate the highly contaminated facility to low radioactivity levels will result in residual radioactivity level well below the limits to permit release of the facility for unrestricted use. An additional cost-benefit consideration relates to decontamination of rooms which are mildly contaminated with radioactivity. Most rooms should not be mildly contaminated with radioactivity in excess of levels which are acceptable for unrestricted facility use since it is assumed that good housekeeping and ALARA practices will be used during facility operations to control the spread of contamination. In areas where there is mild contamination, techniques such as having previously painted surfaces should make decontamination easier and less costly. A source of data for the evaluation of cost for decontamination of mildly contaminated rooms is in NUREG/CR-1754[6] which evaluates decontamination of a number of specific components. As an example, for a hot cell contaminated with Cs-137, the manpower needed for decontamination would be approximately 5 man-days and the associated costs would be approximately $5,000. Costs for decontamination of other specific components would be about the same order. These costs for decontamination of specific mildly contaminated components are small in comparison to the overall decommissioning costs. Therefore, based on the above discussions, while cost-benefit is a consideration, it is not expected to have a major impact on the GEIS results concerning reactor or most nonreactor decommissionings.

Even in situations where the residual radioactivity level might have an effect on decommissioning cost, by use of update provision in the rulemaking it is expected that the decommissioning fund available at the end of facility life will approximate closely the actual cost of decommissioning.

It is imperative that these decommissioning rule amendments in 10 CFR Parts 30, 40, 50, 70, and 72 be issued at this time because it is important to establish financial assurance provisions, as well as other decommissioning planning provisions, as soon as possible so that funds will be available to carry out decommissioning in a manner which protects public health and safety. Based on this need for the decommissioning rule and provisions currently existing and those contained in the rule amendments, the Commission believes that the rule can and should be issued now.

2.6 Financial Assurance

The primary objective of the NRC with respect to decommissioning is to protect the health and safety of the public. An important aspect of this objective is to have reasonable assurance that, at the time of termination of facility operations, adequate funds are available to decommission the facility in a safe and timely manner resulting in its release for unrestricted use, and that lack of funds does not result in delays in decommissioning that may cause potential health and safety problems for the public. The need to provide this assurance arises from the fact that there are uncertainties concerning the availability of funds at the time of decommissioning. The nuclear facility licensee has the responsibility for completing decommissioning in a manner which protects public health and safety. Satisfaction of this objective requires that the licensee provide reasonable assurance that adequate funds for performing decommissioning will be available at the cessation of facility operation.

2.6.1 Present Regulatory Guidance

Present regulatory requirements concerning the degree of financial assurance required of a licensee are not specific enough. 10 CFR 50.33(f) requires that, except for an electric utility applicant for a license to operate a utilization facility, an applicant for a production or utilization facility operating license demonstrate financial capability both to operate the facility and to shut it down and maintain it safely. 10 CFR 50, Appendix F, requires the applicant for a fuel reprocessing plant operating license to demonstrate his financial qualifications "to provide for removal and disposal of radioactive wastes during operation and upon decommissioning." 10 CFR 72 requires an applicant for a license for an independent spent fuel storage installation to provide information on funding for decommissioning. These regulations do not contain sufficient criteria for assuring funds for decommissioning the facilities covered by this EIS.

2.6.2 Implementation of Financial Assurance Requirements

In providing reasonable assurance that funds will be available for decommissioning, there are several possible financing mechanisms, outlined below, which are available to applicants and licensees. The many different types of nuclear facilities present a wide diversity in the cost of decommissioning, in the risk that decommissioning funds might be unavailable, and in the licensees' financial situations. This diversity necessitates that the NRC allow latitude in the implementation of these financing mechanisms. For example, the situation for a large power reactor can be significantly different from that for a small research or testing facility or for a materials license. Generally, for a power reactor, state utility commissions regulate retail rates and the Federal Energy Regulatory Commission regulates wholesale rates, permitting utilities to

recover the cost of providing electricity from their customers. The decommissioning costs are higher than for small facilities, and the licensees are required by 50 CFR 10.54(w) to carry substantial levels of insurance for post-accident decontamination and cleanup. This is significantly different than the situation for a small non-fuel-cycle facility which is not rate regulated and has low decommissioning costs.

In analyzing funding methods, the NRC has developed the following major classification of funding alternatives.

(1) Prepayment - The deposit prior to the start of operation into an account segregated from licensee assets and outside the licensee's administrative control of cash or liquid assets such that the amount of funds would be sufficient to pay decommissioning costs. Prepayment could be in the form of a trust, escrow account, government fund, certificate of deposit, or deposit of government securities.

(2) Surety bonds, letters of credit, lines of credit, insurance, or other guarantee methods - These mechanisms guarantee that the decommissioning costs will be paid should the licensee default. The licensee still must provide funding for decommissioning through some other method. It appears questionable that surety methods of the size necessary and for the time involved with power reactors will be available. However, they appear to be available for facilities that involve smaller costs and periods. The contractual arrangement guaranteeing the surety methods, insurance, or guarantee must include provisions for insuring that these methods will in fact result in funds being available for decommissioning. It should be kept in mind that sureties would only be called if at the time of cessation of facility operation or impending discontinuance of surety by the guarantor, licensee decommissioning funds were inadequate or unavailable.

(3) External sinking funds - A fund established and maintained by setting funds aside periodically in an account segregated from licensee assets and outside the licensee's administrative control in which the total amount of funds would be sufficient to pay decommissioning costs at the time termination of operation is expected. An external sinking fund could be in the form of a trust, escrow account, government fund, certificate of deposit, or deposit of government securities. The weakness of the sinking fund approach is that in the event of premature closure of a facility the decommissioning fund would be insufficient. Therefore, the sinking fund would have to be supplemented by insurance or surety bonds, or letters or lines of credit or other guarantee methods of item (2).

(4) Internal reserve or unsegregated sinking fund - A fund established and maintained by the periodic deposit or crediting of a prescribed amount into an account or reserve which is not segregated from licensee assets and is within the licensee's administrative control in which the total amount of the periodic deposits or funds reserved plus accumulated earnings would be sufficient to pay for decommissioning at the time termination of operation is expected. In this mechanism, the funds are not segregated from the utility's assets, rather they may be invested in utility assets and, at the end of facility life, internal funds are used to pay for decommissioning by, for example, issuance of bonds against licensee assets and the funds raised are used to pay for decommissioning. An internal reserve may also

be in the form of an internal sinking fund which is similar to an external sinking fund except that the fund is held and invested by the licensee. Such a mechanism is generally considered to be less expensive in terms of net present value than the options listed above, although, as discussed below, whichever funding mechanism is used should not have a significant impact on the revenue requirements. The problem with the internal or unsegregated funding method is the lesser level of assurance that funds will be available to pay for decommissioning than the other mechanisms because this method depends on financing internal to the licensee, and therefore, is vulnerable to events that undermine the financial solvency of a utility.

The NRC has considered the use of all of these methods, and in particular internal reserve, in several documents. These include NUREG-0584, Revs. 1-3, "Assuring the Availability of Funds for Decommissioning Nuclear Facilities,"[7] NUREG/CR-1481, "Financing Strategies for Nuclear Power Plant Decommissioning,"[8] and NUREG/CR-3899, "Utility Financial Stability and the Availability of Funds for Decommissioning"[9]. In addition, the Commission held a meeting soliciting public and industry views of decommissioning on September 18, 1984 and the NRC staff has reviewed comments in the area of financial assurance submitted on NUREG-0586, "Draft Generic Environmental Impact Statement on Decommissioning Nuclear Facilities" and submitted in response to the proposed rule on decommissioning (50 FR 5600)[10]

These reports and meetings and public comments considered several factors regarding availability of funds for public utilities in the United States. One factor is that utilities are large, very heavily capitalized enterprises whose rates are comprehensively regulated by the State Public Utility Commissions (PUC) and the Federal Energy Regulatory Commission (FERC). This factor permits the utilities to charge reasonable rates subject to reasonable regulation and rules. In addition, the Commission has taken action recently in the promulgation of 10 CFR 50.54(w) to set requirements to establish onsite property damage insurance for use after an accident. Although these insurance proceeds would not be used directly for decommissioning, they would reduce the risk of a utility being hit by a large demand for funds after an accident. Most utilities are now carrying insurance well in excess of $1 billion. Other factors considered are the long time period before decommissioning takes place during which time reasonable assurance of funds for decommissioning must be maintained, as well as concerns regarding utility solvency and potential problems regarding availability of funds which may occur as a result of bankruptcy.

Before publication of the proposed rule, the NRC evaluated the adequacy of various funding methods in light of financial problems encountered by some utilities which, faced with lower growth in electricity demand than they projected and rapidly increasing costs of construction, had been forced to cancel nuclear plants in advanced stages of construction and the ramifications these conditions, as well as issues related to bankruptcy, could have on a utility's ultimate ability to pay for decommissioning. Details of this evaluation are contained in NUREG/CR-3899, (Ref. 9) prepared by an NRC consultant, Dr. J. Siegel of the Wharton School, University of Pennsylvania.

Based on the results of NUREG/CR-3899 in which it is indicated that internal reserve can be a valid funding method and on the considerations discussed in the Supplementary Information to the Proposed Rule, the proposed decommissioning

rule permitted a range of options, including internal reserve, for providing assurance that sufficient funds are available for decommissioning. However, the Supplementary Information to the proposed rule noted that the regulatory approach for assuring funds for decommissioning had been particularly difficult to resolve and specifically requested additional information and comments in this area. In particular, the Supplementary Information stated that:

> "More specifically, Commissioners Asselstine and Bernthal continue to be concerned about the vulnerability of the internal funding mechanism for decommissioning funds, particularly where the funds are used to purchase assets or reduce existing debt."

Based on this concern, Commissioners Asselstine and Bernthal requested "public comments on the need to consider the possibility of insolvency and its impact on the continued availability of decommissioning funds."

Although commenters did not generally refer specifically to the separate request for comment by Commissioners Asselstine and Bernthal, a number of comments, noted above, were received in this area. Those who disagreed with the inclusion of internal reserve in the rule cited problems with liquidity of the internal reserve and with the future financial viability of utilities with resultant problems in providing decommissioning funds, and stated that the level of assurance is inadequate. In contrast, other commenters agreed with the use of internal reserve citing the fact that the likelihood of instability and insolvency is remote, that utilities have investments, cash flow, and annual earnings which are large in comparison to decommissioning cost, and that the internal reserve does provide reasonable assurance.

As part of the review of the comments, NRC has had NUREG/CR-3899 updated to consider the current situation in the utility industry. This analysis is contained in NUREG/CR-3899, Supplement 1, (Ref. 9) which reviewed six utilities which have been subject to severe financial distress. Based on the analysis, NUREG/CR-3899, Supp. 1 indicates that, since NUREG/CR-3899 was published in 1984, the financial health of the nuclear utilities has improved, with the exception of Public Service of New Hampshire (PSNH), and that from a financial standpoint, use of internal reserve currently provides sufficient assurance of funds for decommissioning. The basis for this conclusion is the fact that the likelihood of future crises developing, although not impossible, is extremely remote; that the total market value of the securities of each of the six utilities studied substantially exceeds its decommissioning costs; that it is not necessarily true that bankruptcy of a utility is tantamount to default on decommissioning obligations; and the potential that the costs of decommissioning would be recognized as a prior obligation with regard to creditors.

Despite these conclusions, Supplement 1 notes that PSNH has said that, unless it undergoes financial restructuring and gets the rate increase it is seeking, it probably would become the first major utility to seek protection under the Bankruptcy Act in nearly 50 years.* In addition, Supplement 1 notes that if PSNH's Seabrook plant becomes operational, the prospects for PSNH greatly improve although bankruptcy still cannot be precluded as a possibility due to

*Subsequent to the preparation of the analysis of NUREG/CR-3899, Supplement 1, PSNH filed a petition in bankruptcy under Chapter 11 of the U.S. Bankruptcy code.

the potential for large rate hikes and resultant defections from its electric system. Hence Supplement 1 concludes that internal reserve should not be allowed for Seabrook until the financial prospects of the utility are clarified and the viability of the corporation insured.

In addition, Supplement 1 noted that it is imperative that, in the case of the sale or other disposition of utility assets, no monies are distributed to any security holders until a fund is established to assure payment for decommissioning. Supplement 1 also recommended changes in Federal and State bankruptcy laws relating to utilities and the inclusion in the prospectus of newly issued securities of an explicit statement of the utility's financial obligations to provide adequate funds for decommissioning. Further, Supp. 1, noted that because of changing economic and financial conditions, the NRC should conduct periodic reviews of the overall financial health of utilities with ongoing and prospective nuclear facilities. If such a review indicates the financial condition of utilities taken as a whole or individually is such that internal reserve does not provide reasonable assurance of funds for decommissioning, then additional rulemaking or other steps should be taken to insure availability of these funds.

The Commission has considered the conclusions in NUREG/CR-3899, Supplement 1, as well as the public comments received on the issue. The Commission's review in this area is confined to its statutory mandate to protect the radiological health and safety of the public and promote the common defense and security which stems principally from the Atomic Energy Act of 1954, as amended, and the Energy Reorganization Act of 1974, as amended. In carrying out its licensing and related regulatory responsibilities under these acts, the NRC has determined that there is a significant radiation hazard associated with nondecommissioned nuclear reactors. The NRC has also determined that the public health and safety can best be protected if its regulations require licensees to use methods which provide reasonable assurance that, at the time of termination of operations, adequate funds are available so that decommissioning can be carried out in a safe and timely manner and that lack of funds does not result in delays that may cause potential health and safety problems. Although the Atomic Energy Act and the Energy Reorganization Act do not permit the NRC to regulate rates or to supersede the decisions of State or Federal agencies respecting the economics of nuclear power, they do authorize the NRC to take whatever regulatory actions may be necessary to protect the public health and safety, including the promulgation of rules prescribing allowable funding methods for meeting decommissioning costs. (See Pacific Gas & Electric v. State Energy Resources Conservation & Development Commission, 461 U.S. 190, 212-13, 217-19 (1983); see also United Nuclear Corporation v. Cannon, 553 F. Supp. 1220, 1230-32 (D.R.I. 1982) and cases cited therein.)

For the foregoing reasons, the Commission continues to be concerned with the use of an internal reserve. The Commission notes the concerns expressed in NUREG/CR-3899, Supp. 1 regarding bankruptcy at PSNH as well as the changing economic and financial conditions discussed in NUREG/CR-3899, Supp. 1. The Commission also notes that many utilities are engaging in diversified financial activities which involve more financial risk and believes therefore it is increasingly important to provide that decommissioning funds be provided on a more assured basis.

In addition, to the extent that a utility is having severe financial difficulties at the time of decommissioning, it may have difficulty in funding an

internal reserve when needed for decommissioning. The Commission recognizes that the market value of the stock of those utilities studied in NUREG/CR-3899 has exceeded decommissioning cost. However, although the law in this area is not fully developed, in the event of bankruptcy there is not reasonable assurance that either unsegregated or segregated internal reserves can be effectively protected from claims of creditors and therefore internal reserves cannot be made legally secure. In addition, because of the nature of the internal reserve, the funds collected are not isolated for use for decommissioning. Instead the utility may use the funds for other unrelated purposes.

For the above reasons, the Commission concludes that the internal reserve does not provide reasonable assurance that funds will be available when needed to pay the costs of decommissioning and hence does not provide reasonable assurance that decommissioning will be carried out in a manner which protects public health and safety. Accordingly, the proposed rule has been modified to eliminate the internal reserve as a possible method of providing funds for decommissioning.

In reaching its conclusion not to permit use of internal reserve for decommissioning, the Commission believes it important not to impose inordinate financial burdens on licensees. The modification to the proposed rule is not expected to impose such a burden for several reasons. First, licensees have 2 years from the effective date of the final rule before they have to submit information regarding financial assurance. Second, the external reserve is a sinking fund accumulated over a period of time. Third, a number of states (accounting for almost 50% of power reactors) already require external funding methods. Fourth, recent changes in the tax laws allowing current deductions for external reserves may reduce the cost differential between internal reserve and external reserve.

In summary, NRC has considered the analysis of NUREG/CR-3899, Supp. 1, as well as the documents discussed above. NRC has also considered pertinent factors affecting funding of decommissioning by electric utilities such as the fact that they are regulated entities providing a basic necessity of modern life, their long history of stability, and the situation which may occur in an actual bankruptcy, and the requirements that utilities maintain over one billion dollars of property insurance which reduces one of the major threats to utility solvency. Based on these considerations, it is the Commission's conclusion that the internal reserve method currently allowed by the proposed rule does not provide a reasonable level of assurance of the availability of funds and that even in the unlikely event of utility bankruptcy, there is not reasonable assurance that a reactor will not become a risk to public health and safety.

Whatever funding mechanism is used, its use requires establishing the cost required for decommissioning a facility. This cost should be included as part of financial provisions submitted by an applicant prior to facility commissioning. To minimize administrative effort while still maintaining reasonable assurance of funding, for certain facilities the financial provisions may be based on setting aside an amount which is at least equal to amounts prescribed in the NRC regulations. These amounts vary for the different facilities covered by the regulations.

As information on decommissioning costs become more definitive in time, due to technology improvements, enhanced decommissioning experience, and inflation/deflation cost factors, a licensee's funding provisions should be updated. In this way, it is expected that the decommissioning fund available at the time of

facility shutdown will not differ significantly from actual costs of decommissioning.

It is difficult to accurately estimate what the projected costs for the various funding mechanisms will be at the time of decommissioning. Based on Battelle cost analyses[3,11] presented in this EIS, for the generic PWR and BWR 1175 MWe reactors, decommissioning costs have been estimated at approximately $105 and $135 million respectively. These estimates do not include the costs of demolition of nonradioactive systems or structures beyond that necessary to terminate the NRC license or the cost of site restoration. This results in a cost of a few tenths of a mill (0.1 cent) per kilowatt-hour when averaged over the expected 30-year reactor operating life. The $105 million cost, while not insignificant, is only a small amount compared to PWR operating capital, perhaps comparable to the cost of a full core reload. Furthermore, whichever funding mechanism used should not have a significant impact on the cost to consumers. One study[8] has estimated that the difference in cost between the various funding mechanisms would result in less than a 1% difference in the total bill of a representative utility customer.

In summary, the NRC objective of protecting the public health and safety requires that there be reasonable assurance of funds for decommissioning. There should not be any significant financial burden on the applicant in providing a funding mechanism for decommissioning costs either through prepayment, surety bonds, a sinking fund, insurance, or some combination thereof.

2.7 Management of Radioactive Wastes and Interim Storage

During the decommissioning of a nuclear facility radioactive waste which was generated during the facility operating lifetime must be disposed of at waste disposal sites. These wastes include equipment and structures made radioactive both by neutron activation and by radioactive contaminants, include radioactive wastes resulting from chemical decontamination of the facility, and include miscellaneous cleaning equipment.

Disposal of these wastes is covered by existing NRC and other applied Federal and State regulations and is beyond the scope of the rulemaking action supported by the EIS. Disposal of spent fuel will be via geologic repository pursuant to requirements set forth in NRC's regulation 10 CFR Part 60. Disposal of low-level wastes is covered under NRC's regulation 10 CFR Part 61. Because low-level wastes cover a wide range in radionuclide types and activities, 10 CFR Part 61 includes a waste classification system that establishes three classes of waste generally suitable for near-surface disposal: Class A, Class B, and Class C. This classification system provides for successively stricter disposal requirements so that the potential risks from disposal of each class of waste are essentially equivalent to one another. In particular, the classification system limits to safe levels the concentrations of both short- and long-lived radionuclides of concern to low-level waste disposal. The radionuclides considered in the waste classification system of 10 CFR Part 61 include long-lived activation products such as Ni-59 or Nb-94, as well as "intense emitters" such as Co-60.

Wastes exceeding Class C limits are considered to be not generally suitable for near-surface disposal, and those small quantities currently being generated are being safely stored pending development of disposal capacity. The recently

enacted Low-Level Radioactive Waste Policy Amendments Act of 1985 (Pub. L. 99-240, approved January 15, 1986, 99 Stat. 1842) provides that disposal of wastes exceeding Class C concentrations is the responsibility of the Federal government. The Act also requires a report by DOE to Congress with recommendations for safe disposal of these wastes. DOE published this report, "Recommendations for Management of Greater than Class C Low-Level Radioactive Waste," DOE/NE-0077, in February 1987.

As far as decommissioning wastes are concerned, technical studies coupled with practical experience from decommissioning of small reactor units indicate that wastes from future decommissionings of large power reactors will have very similar physical and radiological characteristics to those currently being generated from reactor operations. Two of the studies performed by NRC include NUREG/CR-0130, Addendum 3,[3] and NUREG/CR-0672, Addendum 2,[11] which specifically address classification of wastes from decommissioning large pressurized water reactor (PWR) and large boiling water reactor (BWR) nuclear power stations.

These studies indicate that the classification of low-level decommissioning wastes from power reactors will be roughly as shown in Table 2.7-1.

Table 2.7-1 Classification of low-level decommissioning wastes from power reactors

Waste Class	PWR (Vol. %)	BWR (Vol. %)
A	98.0	97.5
B	1.2	2.0
C	0.1	0.3
Above C	0.7	0.2

As shown, the great majority of the waste volume from decommissioning will be classified as Class A waste. Only a small fraction of the wastes will exceed Class C limits.

Transportation of decommissioning wastes will involve no additional technical considerations beyond those for transportation of existing radioactive material. Existing regulations covering transportation of radioactive material are covered under NRC regulations in 10 CFR Parts 20, 71, and 73, and Department of Transportation regulations in 49 CFR Parts 170-189.

An operating 1000 MWe reactor will generate approximately 25.4 MTHM (metric tons of heavy metal) (9.4 m^3) of spent fuel each year and 1300 m^3 of low-level waste each year. When multiplied over the 40-year operating lifetime of the plant, these values can be compared to the 11 m^3 of activated material (greater than Class C) and 17,900 m^3 of low-level waste resulting from DECON of a PWR of similar size (see Section 4.4), and it can be seen that decommissioning will generate an appreciable fraction of the low-level waste generated by a PWR over its lifetime. However, in any given year, the quantity of waste from all operating reactors will considerably exceed that generated from those facilities being decommissioned. The low-level wastes generated in 1980 from commercial nuclear fuel cycle activities totaled 81,000 m^3 and low-level wastes from commercial non-fuel-cycle activities totaled 28,000 m^3. Hence, any problems in waste disposal capacity will be the result primarily of operating nuclear

facility waste inputs rather than decommissioning waste inputs. The following is a discussion of the current situation in this area.

Disposal capacity for Class A, Class B, and Class C wastes currently exists. Development of new disposal capacity under the State compacting process is covered under the Low-Level Radioactive Waste Policy Amendments Act referenced above. This Act provides for incentives for development of such capacity, as well as penalties for failure to develop such capacity. For wastes exceeding Class C concentrations, DOE has offered to accept such waste for storage pending development of disposal criteria and capacity. For spent fuel which as noted in Section 2.4 could impact the decommissioning schedule, a detailed schedule for development of monitored retrievable storage and geologic disposal capacity is provided in the Nuclear Waste Policy Act of 1982.

Hence, based on the above discussion, before decommissioning of a nuclear facility occurs, licensees should assess current waste disposal conditions and their potential impact on decommissioning. Although the DECON decommissioning alternative assumes availability of capacity to dispose of waste, alternative methods of decommissioning are available (e.g., SAFSTOR) including delay in completion of decommissioning during which time there can be temporary storage of wastes. Delay in decommissioning can result in a reduction of occupational dose and waste volume due to radioactive decay.

2.8 Safeguards

Just prior to decommissioning, the same safeguards measures may be required that are required while the facility is operating. During the actual decommissioning, levels of special nuclear material in the facility should be decreased as a result of cleanout of the facility. In the case of DECON, decreased levels of safeguards measures should be continued until the quantity of special nuclear material is reduced below safeguards levels, at which time safeguards measures can be discontinued. Regulations defining required procedures and safeguard levels are found in 10 CFR Part 70 Special Nuclear Materials and 10 CFR Part 73 Physical Protection of Plant and Materials. In the case of SAFSTOR, depending on the quantity of special nuclear material as compared to the safeguards levels, continuous manned security may be required or may be replaced by continuous remote monitoring of intrusion, fire, and radiation alarms during the continuing care period. Immediate response is, of course, required in case any alarm is activated. Engineered barriers, such as fences and high-security locks, are maintained and inspected regularly. Deferred decontamination requires similar safeguards provisions as are required during DECON depending on the quantity of special nuclear material remaining at that time. The long-term care period of ENTOMB requires remote monitoring of intrusion, fire, and radiation alarms and engineered barriers if special nuclear material quantities are above safeguard levels.

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*See footnote to reference in Chapter 1 for document purchasing availability.

4 PRESSURIZED WATER REACTOR

A pressurized water reactor (PWR) is a facility for converting the thermal energy of a nuclear reaction into steam to drive a turbine-generator and produce electricity. The conversion is accomplished by heating water to a high temperature and pressure in the reactor pressure vessel, using the pressurized hot water to produce steam in the steam generator, and driving the turbine-generator with the steam.

The generic site for the reference 1175-MWe PWR is described in Section 3.1. The specific site for a reactor is chosen on the basis of operational and regulatory criteria, some of which are appropriate to decommissioning as well as to reactor construction and operation. For example, transportation access, water supply, and a skilled labor supply are required for construction and operation, and are also necessary for decommissioning. Usually, however, the most suitable decommissioning alternative will not depend upon the generic site description or upon specific siting considerations. Rather it will depend on such factors as desirability of terminating the license, land use considerations at the time of decommissioning, occupational radiation exposures, and costs. The choice of decommissioning alternative may also depend upon whether or not the facility must be decommissioned before normal retirement age because of premature closure. In any event, the particular alternative chosen will depend almost entirely upon circumstances at the time of decommissioning, rather than upon earlier siting considerations.

Much of what follows is based on the NRC-sponsored Pacific Northwest Laboratory (PNL) studies on the technology, safety and cost of decommissioning a PWR.([1,2]) In the parent study,[1] PNL selected the Portland General Electric Company's 1175-MWe Trojan Nuclear Plant at Rainier, Oregon, as the reference PWR and assumed it to be located on a generic site typical of reactor locations. PNL then developed and reported information on the available technology, safety considerations, and probable costs for decommissioning the reference facility at the end of its operating life. Also, as part of an addendum[2] to this study, PNL did a sensitivity analysis to determine the effect that varying certain parameters might have on the conclusions in the original study regarding doses and costs of decommissioning. The parameters that were varied in the addendum included reactor size, degree of radioactive contamination, decommissioning alternatives, etc. The incremental costs of utilizing an external contractor for decommissioning and of additional staff needed to assure that the decommissioning staff do not exceed radiation dose limits have been evaluated in a related follow-on analysis.[3] In another related follow-on study,[4] the estimated decommissioning cost and dose impacts of post-TMI backfit requirements on the reference PWR have been examined and assessed. The results of all of these recent studies are included in the estimated decommissioning cost and dose estimates presented in this chapter for the reference PWR.

4.1 PWR Description

The major components of a PWR are a reactor core and pressure vessel, steam generators, steam turbines, an electric generator, and a steam condenser system

(Figure 4.1-1). Water is heated to a high temperature under-pressure inside the reactor and is then pumped in the primary circulation loop to the steam generator. Within the steam generator, water in the secondary circulation loop is converted to steam that drives the turbines. The turbines turn the generator to produce electricity. The steam leaving the turbines is condensed by water in the tertiary loop and returned to the steam generator. The tertiary loop water then flows to cooling towers where it is, in turn, cooled by evaporation. The tertiary loop is open to the atmosphere, but the primary and secondary cooling loops are not.

Buildings or structures associated with the reference PWR include (1) the heavily reinforced concrete containment building, which houses the pressure vessel, the steam generators, and the pressurizer system, (2) the turbine building, which contains the turbines and the generator, (3) the cooling towers, (4) the fuel building, which contains fresh and spent fuel handling facilities, the spent fuel storage pool and its cooling system, and the solid radioactive waste system, (5) the auxiliary building, which contains the liquid radioactive waste treatment systems, the filter and ion exchanger vaults, the gaseous radioactive waste treatment system, and the ventilation systems for the containment, fuel, and auxiliary buildings, (6) the control building, which houses the reactor control room and personnel facilities, (7) water intake structures, (8) the administration building, and (9) perhaps other structures such as warehouses and nonradioactive shops.

In a PWR, the reactor core and its pressure vessel are highly radioactive. So are the steam generators and the piping between the reactor and steam generators. Because the turbines are not directly connected to the primary loop, they are usually not radioactive unless there has been tube leakage in the steam generators. The cooling towers and associated piping are normally not radioactive. Much equipment in the auxiliary building is radioactive, as is the spent fuel storage pool and its associated equipment.

The major radiation problems in decommissioning are associated with the reactor itself, the primary loop, the steam generators, the radioactive waste handling systems, and the concrete biological shield that surrounds the pressure vessel.

4.2 Reactor Decommissioning Experience

At the present time, the Elk River, Minnesota, demonstration reactor is the only power reactor that has been completely dismantled. This was a 58.2-MWt BWR that was dismantled between 1971 and 1974. Though this reactor was quite small compared to present day commercial power reactors, one lesson stands out: reactors can be decontaminated with reasonable occupational radiation exposure and with virtually no public radiation exposure. At Elk River the containment building was kept intact until the pressure vessel and the biological shield were removed. Only after all of the radioactive metal components and concrete areas were removed, was the concrete containment building demolished. Of particular interest was the development of a remotely operated plasma arc torch that was used for cutting 1½-inch-thick stainless steel under water and 3½-inch-thick carbon steel in air.[5] For large reactors, 1,000-MWe, the cutting of $2^3/_4$-inch-thick stainless steel under water and 9-inch-thick carbon steel in air will be required.[6] Based on current technology, this should easily be accomplished.[7,8]

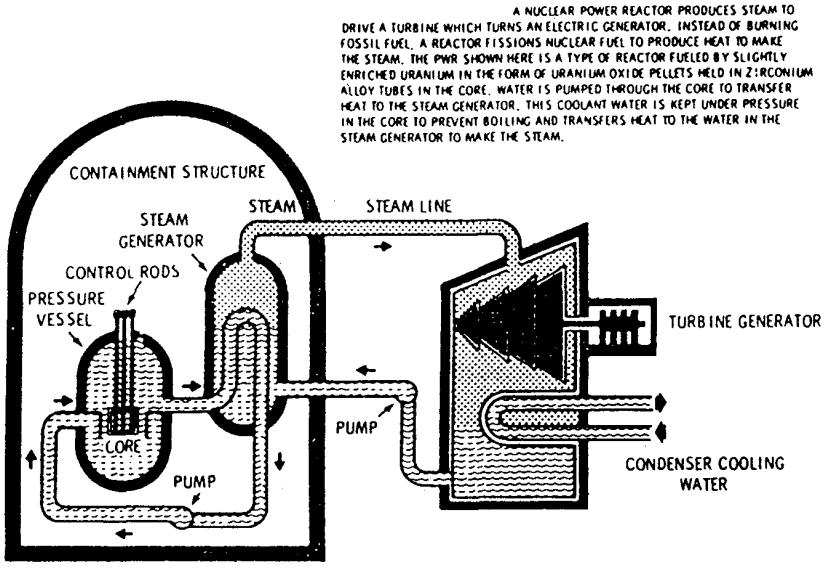

Figure 4.1-1 Pressurized water reactor

Other power reactors, all of them relatively small, have been placed in safe storage or entombed (see Table 1.5-1). These methods of decommissioning require some sort of surveillance as mentioned in Section 2.3, and also require retention of a possession-only license. In the case of the Elk River reactor, its licenses were terminated.

4.3 Decommissioning Alternatives

The decommissioning alternatives considered in this section are DECON, SAFSTOR, and ENTOMB.

4.3.1 DECON

DECON is defined as the immediate removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Nonradioactive equipment and structures need not be torn down or removed as part of a DECON procedure. The end result is the release of the site and any remaining structures for unrestricted use as early as the 6 years estimated for decommissioning after the end of reactor operation.

DECON is advantageous because it allows termination of the NRC license shortly after cessation of facility operations and eliminates a radioactive site. DECON is advantageous if the site is required for other purposes, if the site is extremely valuable, or, if for some reason the site must be immediately released for unrestricted use. It is also advantageous in that the reactor operating staff is available to assist with decommissioning and that continued surveillance and maintenance is not required. A disadvantage is the higher occupational radiation dose which occurs during DECON compared to the other alternatives.

The basic estimates in the original PNL studies have been adjusted by PNL analysts to reflect January 1986 costs. The revised estimate for the reference PWR shows that DECON would require 6 years to complete, including 2 years of planning prior to reactor shutdown, and would cost $88.7 million in 1986 dollars (Table 4.3-1). In addition to the values escalated from the PNL reports (NUREG/CR-0130 and NUREG/CR-0130, Addendum 1), the table also includes the cost additions--for pre-decommissioning engineering, additional staff to assure meeting the 5 rem/year dose limit for personnel, extra supplies for the additional staff, and the additional costs associated with the option of utilizing an external contractor to conduct the decommissioning effort--which were developed in the PNL cost update done for the Electric Power Research Institute.[3] The estimated decommissioning cost impacts of post-TMI-2 requirements on the reference PWR[4] are included in the table as well. It can be seen from the table that the total cost of DECON is about $103.5 million under the utility-plus-contractor option. For comparison purposes, the time required to plan and build a large power reactor is presently about 12 years and the cost is well over two billion dollars.

Three important radiation exposure pathways need to be considered in the evaluation of the radiation safety of normal reactor decommissioning operations: inhalation, ingestion, and external exposure to radioactive materials. For decommissioning workers, external exposure to radioactive materials is the dominant exposure pathway during decommissioning since inhalation and ingestion can be minimized or eliminated as pathways by protective techniques, clothing and breathing apparatus. Inhalation is considered to be the dominant pathway of

Table 4.3-1 Summary of estimated costs for decommissioning the reference PWR in $ Millions [a,b]

Decommissioning Element	DECON[c]	Prep. for Safe Storage[d]	SAFSTOR[e] 10 Years	SAFSTOR[e] 30 Years	SAFSTOR[e] 100 Years	ENTOMB[f] Internals Included (g)	ENTOMB[f] Internals Removed	ENTOMB[f] 100 years of Surveillance (h)
Base Case Estimated Decommissioning Costs: (1978 dollars)	(31.0)	(9.5)	(39.2)	(40.8)	(39.9)	(21.0)	(24.7)	(3.9)
1986 dollars	73.5					38.2	46.6	6.4
Safe Storage Preparation[d]	NA[1]	17.1	21.8	21.8	21.8	NA	NA	
Continuing Care	NA	NA	1.1[d]	3.7[d]	12.6[d]	(h)	(h)	
Deferred Decontamination[d]	NA	NA	69.4	69.4	40.4	NA	NA	
Possible Additional Costs[j]								
• Additional Staff Needed to Reduce Average Annual Radiation Dose to: 5 rem per year	7.5	1.1				3.1	3.9	
• Use of External Decommissioning Contractor[j]	12.9	4.6				10.5	11.4	
• Pre-Decommissioning Engineering: Internal (utility)[j]	5.6	3.4	4.5	4.5	4.5	5.6	5.6	
or External (contractor)	7.4	4.5				7.4	7.5	
• Supplies for Extra Staff (5 rem/yr average dose)[j]	1.2	0.1				0.6	0.7	
• NRC Licensing Activities[j]	>0.1	~0.1	~0.1[k]	~0.3[k]	~1.0[k]	~0.1	>0.1	~1.0
• Post-TMI-2 Impacts: Internal (utility)[l]	~0.8	negligible[n]	~0.8	~0.8	negligible	~0.3	~0.3	~0.3
or								

Table 4.3-1 (Continued)

Decommissioning Element	DECON[c]	Prep. for Safe Storage[d]	SAFSTOR[e] 10 Years	SAFSTOR[e] 30 Years	SAFSTOR[e] 100 Years	ENTOMB[f] Internals Included (g)	ENTOMB[f] Internals Removed	ENTOMB[f] 100 years of Surveillance (h)
External (contractor)[m]	~0.9	negligible				~0.3	~0.3	
Subtotal (<5 rem/yr):								
Utility (Internal) Staffing	88.7	21.8	97.7	100.5	80.3	47.9	57.2	7.4
or								
Contractor (external) Staffing	103.5	27.5				60.2	70.5	7.4
TOTAL Estimated Cost:	88.7		97.7	100.5	80.3			64.6
Utility Staffing	103.5							77.9
or								
Contractor Staffing								

(a) Values include a 25% contingency and are in constant 1986 dollars.

(b) Values exclude cost of disposal of last core, exclude cost of demolition of nonradioactive structures, and exclude cost of deep geologic disposal of dismantled, highly activated components.

(c) Adapted from Reference 1, Table 10.1-1 and Table H.5-2, unless otherwise indicated.

(d) Adapted from Reference 1, Table 2.9-3 and Table H.5-2, unless otherwise indicated.

(e) The values shown for SAFSTOR include the costs of the preparations for safe storage, continuing care, and deferred decontamination.

(f) Adapted from Reference 2, 4.5-1, unless otherwise indicated.

(g) Dose not include the eventual costs associated with the removal, packaging, and disposal of the entombed radioactive materials, the demolition of the entombment structure, or demolition of the Reactor Building.

(h) The annual cost of surveillance and maintenance for the entombed structure is estimated to be about $0.064 million.

(i) NA-not applicable.

(j) Adapted from Reference 3, Table 1.1, unless otherwise indicated.

(k) The values shown include the estimated costs of NRC licensing activities as well as the costs associated with inspections anticipated to be required by other Federal and state agencies.

(l) Adapted from Reference 4, Table 2.5-4.

(m) Adapted from Reference 4, Table 2.5-4 and from Reference 2, Section 6.3.

(n) Negligible means less than $0.025 million.

public radiation exposure, since exposure to radioactive surfaces and ingestion can be minimized or eliminated as radiation pathways to the public during decommissioning. During the transport of radioactive wastes, inhalation and ingestion can be minimized or eliminated as radiation pathways to workers and to the public by techniques similar to those used during decommissioning. Therefore, exposure to radioactive materials is considered to be the dominant mode of radiation exposure to the public and to workers during waste transport. PNL calculated radiation doses for only the dominant pathways, and assumed the radiation doses from other pathways to be essentially zero. A summary of these doses is presented in Table 4.3-2.

The aggregate occupational radiation dose from external exposure to surface contamination and activated material, not including transportation of radioactive waste, is estimated to be about 1115 man-rem over 4 years (Table 4.3-2) or an average of about 279 man-rem per year. The aggregate occupational radiation dose from the transportation of radioactive wastes is estimated to be about 100.2 man-rem to truck transportation workers from DECON waste shipments. For comparison purposes, the average aggregate annual occupational radiation dose from operation, maintenance, and refueling of PWRs from 1974 through 1978 was 550 man-rem per reactor.[9] In 1979 it was 924 man-rems,[10] and in 1980 it was 1,101 man-rems.

This increase is considered to be due to build-up of radioactive contaminants with increasing reactor age[11] and to increasing reactor size[12] and special man-rem intensive maintenance tasks.

The inhalation radiation dose to the public from airborne radionuclide releases during DECON is estimated to be negligible. The radiation dose to the public is calculated to be about 20.6 man-rem from the truck transport of radioactive wastes from DECON.

4.3.2 SAFSTOR

Generally, the purpose of SAFSTOR is to permit ^{60}Co to decay to levels that will reduce occupational radiation exposure during decontamination. As indicated in Table 4.3-2, most of the occupational dose reduction due to decay occurs during the first 30 years after shutdown with considerably less dose reduction thereafter. The public dose, which will always be small, will also experience most of its reduction during the first 30 years. Nonradioactive equipment and structures need not be removed, but eventually all radioactivity in excess of that allowed for unrestricted use of the facility must be removed. Hence, in contrast to DECON, to take advantage of the dose reduction, SAFSTOR could be as long as 60 years including final decontamination. The end result is the same: release of the site and any remaining structures for unrestricted use.

SAFSTOR is advantageous in that it results in reduced occupational radiation exposure in situations where urgent land use considerations do not exist. Disadvantages are that the licensee is required to maintain a possession-only license under 10 CFR Part 50 and to meet its requirements at all times, thus contributing to the number of sites dedicated to radioactive confinement for an extended time period. Other disadvantages are that surveillance is required, the dollar costs are higher than for DECON, and the experienced operating staff may not be available at the end of the safe storage period to assist in the decontamination.

Table 4.3-2 Summary of radiation dose analyses for decommissioning the reference PWR (values are in man-rem)[a,b]

		SAFSTOR			ENTOMB	
	DECON	10 Years	30 Years	100 Years	Internals Included	Internals Removed
Occupational Exposure						
Safe Storage Preparation[c]	NA[j]	282.4[k]	282.4[k]	282.4[k]	NA	NA
Continuing Care[d]	NA	10	14	14	neg.	neg.
Decontamination[e,f]	1,114.5[k]	337.5[k]	24.6[k]	1	NA	NA
Entombment[g]	NA	NA	NA	NA	900	1,000
Safe Stor. Prep. Truck Shipments[h]	NA	10.2	10.2	10.2	NA	NA
Decontamination Truck Shipments[h]	100.2[k]	24.2	1.7	neg.	NA	NA
Entombment Truck Shipments[g]	NA	NA	NA	NA	16	21
Total	1,215[k]	664[k]	333[k]	308[k]	916	1,021
Public Exposure						
Safe Storage Preparation[i]	NA	neg.	neg.	neg.	NA	NA
Continuing Care[i]	NA	neg.	neg.	neg.	neg.	neg.
Decontamination[i]	neg.	neg.	neg.	neg.	NA	NA
Entombment[g]	NA	NA	NA	NA	neg.	neg.
Safe Stor. Prep. Truck Shipments[h]	NA	2.1	2.1	2.1	NA	NA
Decontamination Truck Shipments[h]	20.6[k]	5[k]	0.4	neg.	NA	NA
Entombment Truck Shipments[g]	NA	NA	NA	NA	4	4
Total	21[k]	7[k]	3	2	4	4

Table 4.3-2 (Continued)

(a) All references are from Reference 1, unless otherwise indicated.

(b) Values exclude radiation dose from disposal of the last core.

(c) Table 11.3-2.

(d) Table 11.3-4.

(e) Table 11.3-1.

(f) Table H.6-1.

(g) Tables 3.5-1 and 4.6-1 from Reference 2, with no allowances for radioactive decay (see text for discussion).

(h) Table 11.4-2, with allowances for radioactive decay.

(i) Table 11.2.2.

(j) NA-not applicable.

(k) Values affected by the estimated additional radiation doses due to post-TMI-2 impacts on decommissioning operations. For a detailed explanation of the minor contributions from post-TMI-2 impacts to the total estimates given, consult Table 2.4-1 of Reference 4.

The PNL study shows that the costs of SAFSTOR for a 30-year period are greater than those of DECON and vary with the number of years of safe storage. For example, the total cost of 30-year SAFSTOR is estimated to be $100.5 million in 1986 dollars compared with the total cost of $68.7 million for DECON. However, the total cost of 100-year SAFSTOR is estimated to $80.3 million in 1986 dollars. The lower cost for 100-year SAFSTOR compared to 30-year SAFSTOR is the result of lower costs for deferred decontamination due to the radioactivity having decayed. PNL's cost estimates for the decommissioning alternatives are presented in Table 4.3-1.

SAFSTOR results in lower radiation doses to both the work force and to the public than DECON. The PNL study (Table 4.3-2) shows the aggregate occupational radiation dose to be approximately 321 man-rem for a 30-year SAFSTOR (282.4 man-rem from safe storage preparation, 14 man-rem for continuing care and surveillance, and 24.6 man-rem from deferred decontamination), not including transportation. The occupational radiation dose from the truck transport of radioactive wastes is calculated to be about 12 man-rem. 100-year SAFSTOR results in little additional reduction in the aggregate occupational radiation dose compared to 30-year SAFSTOR.

Radiation doses to the public from airborne radionuclide releases during preparation for safe storage are estimated to be negligible. The radiation dose to the public from the truck transport of radioactive wastes during preparation for safe storage is estimated to be about 2.1 man-rem, and that from the truck transport of radioactive wastes during deferred decontamination after 30 years of safe storage is estimated to be about 0.4 man-rem.

4.3.3 ENTOMB

ENTOMB means the complete isolation of radioactivity from the environment by means of massive concrete and metal barriers until the radioactivity has decayed to levels which permit unrestricted release of the facility. These barriers must prevent the escape of radioactivity and prevent deliberate or inadvertent intrusion. The length of time the integrity of the entombing structure must be maintained depends on the inventory of radioactive nuclides present. A PWR that has been operated only a short time will contain ^{60}Co as the largest contributor to radiation dose and smaller amounts of dominant fission products such as ^{137}Cs with about 30-year half-life. In this case, the integrity of the entombing structure need only be maintained for a few hundred years, as the disappearance of radioactivity is initially controlled by the 5.27-year half-life of ^{60}Co and later by 30-year half-life fission products. If, on the other hand, the reactor has been operated for 30 or 40 years, substantial amounts of ^{59}Ni and ^{94}Nb (80,000-year and 20,000-year half-lives, respectively,) will have been accumulated as activation products in the reactor vessel internals. The dose rate from the ^{94}Nb present in the reactor vessel internals has been estimated to be approximately 2 rem/hour while the dose from the ^{59}Ni in the internals is 0.1 rem/hour. These dose levels are substantially above acceptable residual radioactivity levels and, because of the long half-lifes of ^{94}Nb and ^{59}Ni, would not decrease by an appreciable amount, due to radioactive decay, for thousands of years. In addition, there are an estimated 1,300 curies of ^{59}Ni in the reactor vessel internals which could result in potential internal exposures in the event of a breach of the entombed structure and subsequent introduction of the ^{59}Ni in an exposure pathway during the long half-life of ^{59}Ni. Thus, the long-lived isotopes will have to be removed or the integrity

of the entombing structure will have to be maintained for many thousands of years.

ENTOMB of a PWR is limited to the containment building because its unique structure lends itself to entombment and because it contains most of the radioactivity in the facility. The other radioactive buildings associated with a reactor must be decommissioned by another method such as DECON. It is possible, however, to move some radioactive components from the fuel building or auxiliary building to the containment building and entomb them there, rather than ship them offsite.

ENTOMB is advantageous because of reduced occupational and public exposure to radiation compared to DECON, because little surveillance is required, and because little land is required. It is disadvantageous because the integrity of the entombing structure must be assured in some cases for hundreds of thousands of years, because a possession-only license under 10 CFR Part 50 would be required, and because entombing contributes to the number of sites permanently dedicated to radioactive materials containment.

PNL considered two approaches to entombment in an addendum[2] to its earlier PWR study.[1] In both approaches, as much solid radioactive material from the entire facility as can be accommodated is sealed in the containment building beneath the operating floor by means of a continuous concrete slab. All openings to the exterior beneath the operating floor are sealed. Above the operating floor, radioactive materials are removed to sufficiently permit release of that portion of the facility for unrestricted use.

In the first approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are entombed, along with other radioactive material. This results in less cost and radiation exposure because the pressure vessel and its internals will not have to be removed, dismantled, and transported to a deep geologic waste repository. It will also, however, result in the requirement for a possession-only license and surveillance in perpetuity because of the presence of the long-lived isotopes. Because of the many variables involved, PNL made no firm estimate of the costs for possible deferred dismantlement of the entombment structure. However, these costs are anticipated to be at least of the same order of magnitude as those for deferred dismantlement of the reference PWR after a period of safe storage (see Table 4.3-1).

In the second approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are removed, dismantled, and transported to a radioactive waste repository (a careful inventory of radioactivity would need to be made to ensure that only relatively short-lived isotopes remained). This approach results in more cost and radiation dose, but offers the possibility that surveillance and the possession-only license could be terminated at some time within several hundred years, thereby releasing the entire facility for unrestricted use.

Radioactive materials not entombed would have to be packaged and transported to a disposal site. Costs and radiation doses for this portion of the entombment procedure would be the same as for DECON. Cost savings and radiation dose reductions result from a lesser volume of radioactive equipment and material having to be dismantled, packaged, and transported. In all cases, spent fuel would be removed.

ENTOMB for the reference PWR, including the pressure vessel and its internals, is estimated to cost $47.9 million, with an annual maintenance cost of $64,000. It results in an aggregate radiation dose of 900 man-rem to decommissioning workers, 16 man-rem to transportation workers, and 4 man-rem to the general public. ENTOMB for the reference PWR, with the pressure vessel internals removed, is estimated to cost $57.2 million with an annual maintenance cost of $64,000, and to result in an aggregate radiation dose of 1000 man-rem to decommissioning workers, 21 man-rem to transportation workers, and 4 man-rem to the general public. These estimates are listed in Tables 4.3-1 and 4.3-2.

Although task-wise schedules were developed for DECON,[1] no comparable schedules were developed for the ENTOMB analysis.[2] As a result, the estimated occupational exposures shown in Table 4.3-2 are not decay-corrected; thus, they represent conservative, upper-bound estimates.

4.3.4 Sensitivity Analyses

An addendum to the initial PNL study was developed[2] to analyze a variety of realistic decommissioning situations that might significantly impact on the original conclusions regarding doses and costs for the various decommissioning alternatives. While there were some differences in results, the conclusion of the sensitivity analysis is that these differences do not substantially affect the original cost and dose conclusions. Of the various situations analyzed by PNL in the addendum, the most important with regard to their potential effect on dose and cost estimates are reactor size and degree of contamination.

Based on an analysis[11] similar to that for the reference PWR (NUREG/CR-0130 Addendum 1) and incorporating selected cost adders (described in References 3 and 4 and escalated to constant 1986 dollars as shown in Table 4.3-1), upper-bound estimates were made of the costs for immediate dismantlement of reactor plants smaller than the reference plant. The analysis was limited to plants with thermal power ratings greater than 1200 MWt and was based on the assumption that all costs (staff labor, equipment, supplies, etc.) except radioactive waste disposal are independent of plant size. The results are shown in Table 4.3-3.

Table 4.3-3 Estimated immediate dismantlement costs for plants smaller than the reference PWR, based on previously-derived overall scaling factors[a,b] (millions of dollars)

Reactor	MWt.	Waste Disposal	Scaling Factor	Remaining Costs	Escalated Adders	Total Costs[c]
Trojan	3500	40.223	1.000	34.174	14.385	88.782
Turkey Pt.	2550	40.223	0.789	34.174	14.385	80.295
R. E. Ginna	1300	40.223	0.518	34.174	14.385	69.395

(a) All costs are in constant 1986 dollars and include a 25% contingency.

(b) Derivation of previously-derived overall scaling factors can be found in Reference 2.

(c) Total costs shown above are for the utility-only cost option.

Using the results from Table 4.3-3, a linear equation can be derived for the scaling of the immediate dismantlement costs for plants in the 1200 to 3500 MWt range:

$$\text{Cost} = 57.911 + (8.808 \times 10^{-3})(\text{MWt})$$

Revised overall scaling factors for the Turkey Point and Ginna plants were obtained by dividing the results of the linear equation by the cost of the reference plant. Based on this formula, a list of variations in dose and cost for these PWRs is presented in Table 4.3-4.

The addendum[2] also analyzed the sensitivity of decommissioning costs and radiation doses related to a postulated tripling of radiation dose rates from radionuclides deposited in PWR coolant system piping during reactor operation over a period of 30 to 40 years. This tripling of dose rate is postulated as an upper limit on the basis of recent trends for operating reactors. If no corrective action is taken to reduce the radiation dose rates, the accumulated radiation dose to decommissioning workers for DECON would be increased about 1,250 man-rem[(a)], and the total decommissioning costs could be increased by about $5.2 million for DECON. For ENTOMB the radiation dose would be nearly doubled and the total cost could be increased about $3.6 million. For preparations for safe storage, the radiation dose would be increased about 130 man-rem, and there would be no significant change in the cost. If corrective action is taken, such as an extended chemical decontamination cycle, the total additional cost could be about $170,000.

In order to handle these postulated higher initial radiation levels, it appears that additional chemical decontamination during decommissioning would be the most cost-effective approach. For example, it is estimated that increasing the circulation time of the chemical solution about 50% would reduce the postulated increased radiation levels by a factor of 3, thus reducing these levels to approximately the same dose rate conditions assumed in the reference case analysis. This approach would also be more consistent with the principles of ALARA, since the occupational radiation dose associated with a chemical decontamination cycle is relatively small, compared with the radiation dose associated with installing temporary shielding, or with attempting to perform the dismantlement without additional shielding. In addition, it appears likely that the large buildups of radionuclides prevalent today on piping systems will be prevented as periodic decontamination during normal operation of the reactor coolant system and related fluid-handling systems become standard procedures when the present technology development for decontamination solutions has been completed.

One of the circumstances that has changed since the original PWR decommissioning reports[1,2] were prepared which could influence the development of the cost and dose estimates presented in this GEIS is an assessment of post-TMI-2 requirements on the decommissioning of the reference PWR. Actions judged necessary by the NRC to correct or improve the regulation and operation of nuclear power plants based on the experience from the accident at TMI-2 resulted in a number of recommendations that were subsequently issued to the utilities as requirements. Some of those requirements resulted in equipment and hardware changes and/or additions to the reference PWR that could eventually expand the

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(a) This number excludes removal of last core and allows for radioactive decay.

Table 4.3-4 Estimated costs and occupational radiation doses for decommissioning different-sized PWR plants[a,b]

		Station		
		R. E. Ginna	Turkey Point	Trojan
Power Rating	(thermal megawatts)	1.300	2.550	3.500
Overall Scaling Factor	(OSF[MWt])	0.781	0.905	1.000
DECON	($ millions)	69.3	80.3	88.7
	(man-rem)	1097.	1.271	1.404
ENTOMB[d]				
w/internals	($ millions)[d]	37.4	43.3	47.9
	(man-rem)	703	815	900
w/o internals	($ millions)	44.7	51.8	57.2
	(man-rem)	781	905	1.000
SAFSTOR				
Preparations for Safe Storage	($ millions)	17.0	19.7	21.8
	(man-rem)	333	386	426
Safe Storage				
for 30 years	($ millions)	3.7	3.7	3.7
	(man-rem)	14	14	14
for 50 years	($ millions)	6.2	6.2	6.2
	(man-rem)	14	14	14
for 100 years	($ millions)	12.6	12.6	12.6
	(man-rem)	14	14	14
Deferred Dismantlement:				
after 30 years	($ million)	54.2	62.8	69.4
	(man-rem)	23.4	27.2	30
after 50 years	($ million)	31.6	36.7	40.5
	(man-rem)	1.9	2.2	2.4
after 100 years	($ million)	31.6	36.6	40.4
	(man-rem)	0.9	1.1	1.2

(a) Values include a 25% contingency and are in 1986 dollars.

(b) Costs do not include spent-fuel disposal or demolition of nonradioactive structures.

(c) Doses are taken from Ref. 2 and do not include transportation doses and do not take credit for radioactive decay during decommissioning.

(d) Entombment costs do not include continuing care cost ($0.064 M/yr.).

scope of decommissioning activities, since those materials could reasonably be expected to become contaminated or radioactive during the remaining operational lifetime of the plant. For the reference PWR, it was concluded by PNL in a recent study[4] that the original immediate dismantlement decommissioning cost estimates could be expected to increase only slightly overall (less than 1% in constant 1986 dollars), due to a slightly expanded scope of decommissioning activities associated with changes in the reference plants characteristics. The radiation dose would be increased by about 32 man-rem, due largely to the dismantling operations associated with the removal of a significantly greater mass of spent fuel pool storage racks.

There are many areas where various planned design and operational features could facilitate decommissioning. Exploration of such areas was considered by PNL[1] in their initial decommissioning study. It was concluded that appropriate measures could not only significantly reduce decommissioning occupational dose and radioactively contaminated waste volume but could also reduce occupational dose during reactor operation. Preliminary considerations of various design and operational features that could further facilitate decommissioning and their impacts on doses and costs are discussed in NUREG/CR-0569.[14]

4.4 Environmental Consequences

Radiation doses and costs associated with possible decommissioning alternatives are discussed in Section 4.3. It is noted for perspective that in the cases of DECON and SAFSTOR, the environmental effects of greatest concern (i.e., radiation dose and radioactivity released to the environment) are substantially less than the same effects resulting from reactor operation and maintenance. It should also be noted that while the dollar costs of ENTOMB are less than those of DECON, the environmental impacts could be quite high should large amounts of radioactivity escape from a breached structure during the entombment period.

Other environmental consequences are rather different from the environmental consequences usually discussed in environmental impact statements. This is because, usually, an environmental impact statement is addressed to the consequences of building a facility that will require land, labor, capital investment, materials, continuing use of air, water, and fuel; a socio-economic infrastructure; and so on. Decommissioning, on the other hand, is an attempt to restore things to their original condition, which requires a much smaller commitment of resources than did building and operating the facility.

A major environmental consequence of decommissioning, other than radiation dose and dollar cost, is the commitment of land area to the disposal of radioactive waste. PNL made estimates (shown in Table 4.4-1) of the low-level waste disposal volume required to accommodate radioactive waste and rubble removed from the facility and transported to a licensed site for disposal. Reduction in waste volume for SAFSTOR occurs as many of the contamination and activation products present in the facility will have decayed to background levels. The volume for ENTOMB does not include the volume of the entombing structure or of the wastes entombed within it, only the wastes shipped off-site. The entombing structure is, in effect, a new radioactive waste burial ground, separate and distinct from the ones in which the wastes listed in Table 4.4-1 are buried, and may necessitate licensing considerations such as for a low-level waste burial ground under (10 CFR 61).

Table 4.4-1 Estimated burial volume of low-level radioactive waste and rubble for the reference PWR

Decommissioning Alternative		Volume (m^3)
DECON		18,340
SAFSTOR		
Deferred Decontamination[b] following Safe Storage for:	10 Years	18,340[a]
	30 Years	18,340[a,c]
	50 Years	1,830
	100 Years	1,780
ENTOMB[d]		1,740

[a] Includes about 440 m^3 of radioactive waste attributable to removal of back-fitted material adapted from Table 5.1-9, Reference 4).

[b] Radioactive wastes from preparation for safe storage and during safe storage are small in comparison to those of deferred decontamination.

[c] Although, in actuality, there is a gradual decrease in waste volume over time, it is not indicated here for clarity of presentation.

[d] Does not include the volume of the entombing structure or of the wastes within.

If shallow-land burial of radioactive wastes in standard trenches is assumed, then a burial volume of 18,340 m^3 of radioactive waste can be accommodated in less than 2 acres. The two acres is small in comparison with the 1,160 acres used as the site of the reference PWR.

Certain highly activated components of the reactor and its internals may require disposal in a deep geologic disposal facility rather than in a shallow-land burial ground because of the large initial level of radioactivity and the very long half-lives of ^{59}Ni and ^{94}Nb. Only about 11 m^3 of material would be involved and would required approximately 88 m^3 of waste disposal space. The cost for disposing of these materials in deep geologic disposal was estimated by PNL to be about $2.8 million (in 1978 dollars).[1] Based on recent estimates of deep geologic disposal costs,[13] it is currently estimated by PNL that deep geologic disposal of the highly activated materials would cost about $6 million (in 1986 dollars). This latter estimate is based on recent estimates of deep

geologic disposal costs conducted by Pacific Northwest Laboratory for the Department of Energy.[12] This cost has not been included in the costs of decommissioning shown in Table 4.3-1.

PNL considered accidental releases of radioactivity both during decommissioning and during transport of wastes. Radiation doses to the maximum-exposed individual from accidental airborne radioactivity releases during decommissioning operations were calculated to be quite low (Table 4.4-2). Radiation doses to the maximally-exposed individual from accidental radioactivity releases resulting from truck accidents were calculated to be moderate for the most severe accident (Table 4.4-3).

Other environmental consequences of decommissioning are minor compared to the environmental consequences of building and operating a PWR. Water use and evaporation at the rate of as much as 27×10^6 m^3/yr ceased when the reactor ceased operation. The total water use for decommissioning is estimated to be about 18×10^3 m^3. The number of workers on site at any time will be no greater than when the PWR was in operation and will be much less than when the PWR was under construction. The transportation network is already in place, but will require some maintenance if the SAFSTOR alternative is selected.

Disturbance of the ground cover need not take place to any appreciable extent except for filling holes and leveling the ground following removal of underground structures, unless extended operation of the plant has resulted in contamination of the ground around the plant. Plowing of the ground would generally result in lowering average soil contamination levels to those acceptable for releasing the site for unrestricted use, except for a few more highly contaminated areas where material would have to be removed. In this case, soil to a depth of several centimeters and some paving may have to be removed, packaged, and shipped to a disposal facility before the site can be released for unrestricted use.

The biggest socioeconomic impact will have occurred before decommissioning started, at the time the plant ceased operation and the tax income created by the plant was reduced. No additional public services will be required because the decommissioning staff will be somewhat smaller than the operating staff. In the case of deferred decontamination, the decontamination staff will be larger than the surveillance staff.

4.5 Comparison of Decommissioning Alternatives

From careful examination of Tables 4.3-1 and 4.3-2 it appears that DECON or 30-year SAFSTOR are reasonable options for decommissioning a PWR. 100-year SAFSTOR is not considered a reasonable option since it results in the continued presence of a site dedicated to radioactivity containment for an extended time period with little benefit in aggregate dose reduction compared to 30-year SAFSTOR. DECON costs less than SAFSTOR and its larger annual occupational radiation dose, which is similar to the routine annual dose from plant operations is considered of marginal significance to health and safety.

Either ENTOMB option requires indefinite dedication of the site as a radioactive waste burial ground. In the ENTOMB option with the reactor internals and its long-lived activation products entombed, the security of the site could not be assured for thousands of years necessary for radioactive decay, so this option

Table 4.4-2 Summary of radiation doses to the maximally-exposed individual from accidental airborne radionuclide releases during decommissioning operations

Incident	DECON					Preparations for Safe Storage				
	Airborne Release (μCi)	First-Year Dose (mrem)		Fifty-Year Dose Commitment (mrem)		Airborne Release (mCi)	First-Year Dose (mrem)		Fifty-Year Dose Commitment (mrem)	
		Total Body(a)	Lung	Total Body	Lung		Total Body(a)	Lung	Total Body	Lung
Explosion of LPG Leased from a Front End Loader	3.6×10^{3}	3.6×10^{-2}	4.7×10^{-2}	4.4×10^{-2}	5.4×10^{-2}	---(c)				
Explosion of Oxyacetylene During Segmenting of the Reactor Vessel Shell	3.6×10^{2}	4.3×10^{-5}	6.1×10^{-3}	6.9×10^{-3}	6.9×10^{-3}	---				
Explosion and/or Fire in the Ion Exchange Resin	3.8×10^{1}	3.8×10^{-4}	5.0×10^{-4}	4.6×10^{-4}	5.7×10^{-4}	---				
Gross Leak during In Situ Decontamination	2.1×10^{1}	2.1×10^{-4}	2.8×10^{-4}	2.5×10^{-4}	3.2×10^{-4}	2.1×10^{1}	2.1×10^{-4}	2.8×10^{-4}	2.5×10^{-4}	
Segmentation of RCS Piping With Unremoved Contamination	1.1×10^{1}	4.6×10^{-6}	7.3×10^{-4}	4.8×10^{-6}	7.9×10^{-4}	---				
Loss of Contamination Control Envelope During Oxyacetylene Cutting of the Reactor Vessel Shell	2.3×10^{0}	---	---	---	4.4×10^{-4}	---				
Vacuum Bag Rupture	---					1.0×10^{0}	1.1×10^{-6}	1.3×10^{-5}	1.2×10^{-5}	
Accidental Cutting of Contaminated Piping	---					1.8×10^{-1}	---	1.2×10^{-5}	---	
Accidental Spraying of Concentrated Contamination With the High Pressure Spray	---					1.2×10^{-1}	---	1.6×10^{-6}	1.5×10^{-6}	

(a) The average annual total body dose to an individual in the U.S. from natural sources ranges from 80 to 170 mrem. United Nations Scientific Committee on the Effects of Atomic Radiation, Ionizing Radiation: Levels and Effects. Volume 1, United Nations, pp. 29-63, 1972.

(b) Frequency of occurrence: high $>1.0 \times 10^{-2}$; medium 1.0×10^{-2} to 1.0×10^{-5}; low $<1.0 \times 10^{-5}$ per year.

(c) A dash indicates a dose less than 1.0×10^{-6} mrem or that this action does not apply to the decommissioning mode shown.

Table 4.4-3 Estimated frequencies and radioactivity releases for selected truck transport accidents

Accident Description	Frequency of Accidents per DECON	Frequency of Accidents per SAFSTOR	Release, Curies	Radiation Dose for Maximally Exposed Individual, (rem)(a)			
				1st Year Dose		50 Yr Dose Commitment	
				Bone	Lung	Bone	Lung
Truck Transport of Decommissioning Wastes(b),(c)							
Minor Accident with Closed Van	8.8×10^{-1}	9.0×10^{-2}	No Release	--	--	--	--
Moderate Accidents with Closed Van	2.1×10^{-1}	2.1×10^{-2}	1×10^{-4}	0.01	0.2	0.01	0.2
Severe Accieent with Closed Van	5.6×10^{-3}	5.7×10^{-4}	1×10^{-2}	1.1	21	1.1	24

(a) Maximally-Exposed individual is assumed at 100 m from the site of the accident.

(b) Based on an inventory of 100 Ci per truck shipment.

(c) Release fractions for respirable material for moderate and severe accidents are assumed to be 10^{-6} and 10^{-4} respectively.

is not considered viable. In the ENTOMB option with the reactor internals removed, it may be possible to release the site for unrestricted use at some time within the order of a hundred years if calculations demonstrate that the radioactive inventory has decayed to acceptable residual levels. However, even this ENTOMB alternative appears to be less desirable than either DECON or SAFSTOR based on consideration of the fact that ENTOMB results in higher radiation exposure and higher initial costs than 30-year SAFSTOR, that the overall cost of ENTOMB over the entombment period is approximately the same as DECON, and the fact that regulatory changes occurring during the long entombment period might result in additional costly decommissioning activity in order to release the facility for unrestricted use.

Consideration was given to the situation where, at the end of the reactor operational life, it is not possible to dispose of waste offsite for a limited period of time, but not exceeding 100 years (see Section 2.7). Such a constraint needs to be accounted for in the decommissioning alternatives. Based on an analysis by PNL of the technology, safety and cost considerations on selection of decommissioning alternatives,[14] it was concluded that SAFSTOR is an acceptably viable alternative. While DECON and conversion of the spent fuel pool to an independent spent fuel storage pool is certainly a possibility for the case where all other radioactive wastes can be removed offsite, there does not appear to be any significant safety difference between this alternative and SAFSTOR and the choice should be a licensee decision. The active phase of maintaining the spent fuel in the pool is not considered to be part of the regulatory requirements for decommissioning, but would be considered under the usual operating licensing aspects regarding health and safety with consideration given to facilitation for decommissioning. Aside from the expenses incurred from storing spent fuel, other costs for keeping radioactive wastes onsite for the reactor in a safe storage mode were estimated to have minimal effect on the SAFSTOR alternative compared to this alternative for radioactive wastes being sent offsite. Site security for storage of spent fuel (which is considered as an operational rather than a decommissioning consideration) was estimated at about $0.94 million per year (in 1986 dollars)[(a)]. In a multireactor site, such security could result in less cost because of a sharing of required overheads.

(a) Adapted from Reference 14.

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*See footnote to reference in Chapter 1 for document purchasing availability.

13. R. L. Engel et al., 1986. 1986 Annual Review of the Adequacy of the 1.0 mill per kWh Waste Disposal Fee, PNL-5877, Pacific Northwest Laboratory. Richland, Washington.

14. G. M. Holter, Technology Safety and Costs of Decommissioning a Reference Pressurized Water Reactor Power Station, Addendum 2 to NUREG/CR-0130, Effects on Decommissioning of an Interim Inability to Dispose of Wastes Offsite, Prepared by Pacific Northwest Laboratory for U.S. Nuclear Regulatory Commission, July 1983.

5 BOILING WATER REACTOR

A boiling water reactor (BWR), like a pressurized water reactor (PWR), is a facility for converting the thermal energy of a nuclear reaction into the kinetic energy of steam to drive a turbine-generator and produce electricity. In a BWR, the conversion is accomplished by heating water to boiling in the reactor pressure vessel and using the resulting steam to drive the turbines. The intermediate step, present in a PWR, of converting pressurized hot water into steam through a heat exchanger in a steam generator is not used in a BWR. Elimination of this step also eliminates one cooling loop.

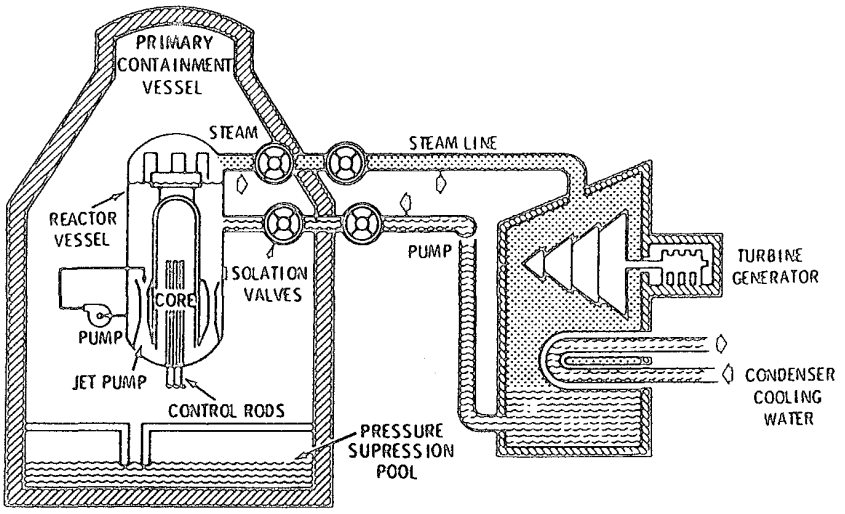
The generic site for the reference 1155-MWe BWR is assumed to be typical of reactor locations and is described in Section 3.1. As in the case of a PWR, the specific site for a BWR is chosen on the basis of operational and regulatory criteria, usually with little regard for decommissioning. Fortunately, factors that are appropriate for siting, such as transportation access, water supply, and skilled labor supply, are also appropriate for decommissioning. Thus, the decommissioning alternative chosen will not usually depend on siting considerations, but rather on safety, costs, and land use options at the time of decommissioning. These considerations are discussed in Section 4 for a PWR, and apply equally to a BWR.

In this section, we have used information prepared for the study on the technology, safety and costs of decommissioning a reference BWR, which was conducted by Pacific Northwest Laboratory (PNL) for the NRC.[1] In the BWR study, PNL selected the Washington Public Power Supply System's WNP-2 1155-MWe reactor at Hanford, Washington, as the reference BWR and assumed it to be located on the generic site. PNL then developed and reported information on the available technology, safety considerations, and probable costs for decommissioning the reference facility at the end of its operating life. As part of this study, PNL did a sensitivity study to analyze the effect that variation of certain parameters might have on radiation doses and costs associated with decommissioning. The parameters which were varied included reactor size, degree of radioactive contamination, different contract arrangements, type of containment structure, etc.

The incremental costs of utilizing an external contractor for decommissioning were updated in a related follow-on analysis.[2] In another related follow-on study,[3] the estimated decommissioning cost and dose impacts of post-TMI-2 requirements on the reference BWR have been examined and assessed. The results of these two recent studies are included in the estimated decommissioning cost and dose estimates presented in this chapter for the reference BWR.

5.1 Boiling Water Reactor Description

The major components of a BWR are a reactor core and pressure vessel, steam turbines, an electric generator, and a steam condenser system (Figure 5.1-1). Water is boiled in the reactor pressure vessel to create steam at high temperature and pressure, which then passes through the primary circulation loop to drive the turbines. The turbines turn the generator, which produces electricity.



A NUCLEAR POWER REACTOR PRODUCES STEAM TO DRIVE A TURBINE WHICH TURNS AN ELECTRIC GENERATOR. THE BWR SHOWN HERE IS A TYPE OF REACTOR FUELED BY SLIGHTLY ENRICHED URANIUM IN THE FORM OF URANIUM OXIDE PELLETS HELD IN ZIRCONIUM ALLOY TUBES IN THE CORE. WATER IS PUMPED THROUGH THE CORE, BOILS, AND PRODUCES STEAM THAT IS PIPED TO THE TURBINE.

Figure 5.1-1 Boiling water reactor

The steam leaving the turbines is condensed by water in the secondary loop and flows back to the reactor. The water in the secondary loop flows to the cooling towers where it is in turn cooled by evaporation. The secondary cooling loop is open to the atmosphere, but the primary loop is not.

Buildings or structures associated with the reference BWR include 1) the reactor building which houses the reactor pressure vessel, the containment structure, the biological shield, new and spent fuel pools, and fuel handling equipment; 2) the turbine generator building which houses the turbines and electric generator; 3) the radwaste and control building which houses the solid, liquid, and gaseous radioactive waste treatment systems, and the main control room; 4) the cooling towers; 5) the diesel generator building which houses auxiliary diesel generators; 6) water intake structures and pump houses; 7) the service building which houses the makeup water treatment system, machine shops, and offices; and 8) other minor structures.

In reference BWR, the reactor building, the turbine generator building, and the radwaste building are the only buildings containing radioactive materials. The reactor core and its pressure vessel are highly radioactive, as is the piping to the turbines. The turbines are also radioactive, but the cooling towers and associated piping are not, since the design of the system is such that any leakage would be from the nonradioactive secondary loop to the primary loop. Much equipment in the radwaste building is radioactively contaminated, as is the spent fuel pool in the reactor building.

The major sources of radiation in decommissioning a BWR are associated with the reactor itself, the containment structure, the concrete biological shield, the primary loop, the turbines, and the radwaste handling systems.

5.2 BWR Decommissioning Experience

At the present time, the Elk River, Minnesota, demonstration reactor is the only power reactor that has been completely dismantled.[4] This was a 58.2-MWt BWR that was dismantled between 1971 and 1974. While this reactor was quite small compared to present-day power reactors, its decommissioning served to demonstrate that reactors can be decontaminated safely with little occupational or public risk. At Elk River, the containment building was kept intact until the pressure vessel and biological shield were removed. Only after all of the radioactive metal components and concrete areas were removed was the concrete containment structure demolished.

Other reactors, all of them relatively small, have been placed in safe storage or entombed (Table 1.5-1). Safe storage and entombment require surveillance and retention of a possession-only license. At Elk River, the license was terminated.

5.3 Decommissioning Alternatives

The decommissioning alternatives considered in this section are DECON, SAFSTOR, and ENTOMB.

5.3.1 DECON

DECON means the prompt removal and disposal of all radioactivity in excess of levels which would permit release of the facility for unrestricted use. Non-radioactive equipment and structures need not be torn down or removed as part of a DECON procedure. The end result is the release of the site and any remaining structures for unrestricted use as early as 6 years after the end of reactor operation.

DECON is advantageous because it allows termination of the NRC license shortly after cessation of facility operations and eliminates a radioactive site. DECON is advantageous if the site is required for other purposes, if the site has become extremely valuable, or if the site for some reason must be immediately released for unrestricted use. It is also advantageous in that the reactor operating staff is available to assist with decommissioning and that continued surveillance and maintenance is not required. A disadvantage is the higher occupational radiation dose which occurs during DECON compared to the other alternatives.

The basic estimates in the original PNL studies have been adjusted by PNL analysts to reflect January 1986 costs. The revised estimate for the reference BWR shows that DECON would require 6 years to complete, including 2 years of planning prior to reactor shutdown, and would cost $108.9 million in 1986 dollars (Table 5.3-1). In addition to the values escalated from the PNL report (NUREG/CR-0672),[1] the table also includes the cost additions--for pre-decommissioning engineering, additional staff to assure meeting the 5 rem/year dose limit for personnel, extra supplies for the additional staff, and the additional costs associated with the option of utilizing an external contractor to conduct the decommissioning effort--which were developed in the PNL cost update done for the Electric Power Research Institute.[2] The estimated decommissioning cost impacts of post-TMI-2 requirements on the reference BWR[3] are included in the table as well. It can be seen from the table that the total cost of DECON is about $131.8 million under the utility-plus-contractor option. For comparison purposes, the time required to plan and build a large power reactor is presently about 12 years and the cost is well over two billion dollars.

Three important radiation exposure pathways need to be considered in the evaluation of the radiation safety of normal reactor decommissioning operations: inhalation, ingestion, and external exposure to radioactive materials. For reasons similar to that discussed for PWRs in Section 4.3.1, during decommissioning the dominant exposure pathway to workers is external exposure while for the public the dominant exposure pathway is inhalation. During the transport of radioactive waste, the dominant exposure pathway is external exposure for both transportation workers and the public. A summary of the radiation doses resulting from these pathways is presented in Table 5.3-2.

The aggregate occupational radiation dose from external exposure to surface contamination and activated material, not including transportation of radioactive waste, is estimated to be about 1764 man-rem over 4 years, or an average of 440 man-rem per year. (Table 5.3-2). The occupational radiation dose to truck transportation workers from DECON waste shipments is estimated to be

Table 5.3-1 Summary of reevaluated decommissioning costs for the reference BWR in $ Millions [a,b]

Decommissioning Element	DECON[c]	Prep. for Safe Storage[d]	SAFSTOR[e] 10 Years	SAFSTOR[e] 30 Years	SAFSTOR[e] 100 Years	ENTOMB[f] Internals Included (g)	ENTOMB[f] Internals Removed	100 years of Surveillance (h)
Base Case Estimated Decommissioning Costs:								
(1978 dollars)	(43.6)	(21.3)	(57.4)	(58.9)	(55.0)	(35.0)	(40.6)	(3.9)
1986 dollars	98.5					68.7	81.4	6.4
Safe Storage Preparation[d]	NA[1]	37.5	41.0	41.0	41.0	NA	NA	
Continuing Care	NA	NA	0.9[j]	3.3[j]	11.6[j]	(h)	(h)	
Deferred Decontamination[d]	NA	NA	82.2	82.2	48.0	NA	NA	
Possible Additional Costs[j]								
• Additional Staff Needed to Reduce Average Annual Radiation Dose to: 5 rem per year	4.4	1.1				2.7	2.3	
• Use of External Decommissioning Contractor[l]	21.1	8.8				17.8	21.3	
• Pre-Decommissioning Engineering: Internal (utility)[l]	5.6	3.4	4.5	4.5	4.5	5.6	5.6	
or External (contractor)	7.4	4.5				7.4	7.5	
• Supplies for Extra Staff (5 rem/yr average dose)[j]	.02	0.1				~0.1	~0.1	
• NRC Licensing Activities[m]	>0.1	~0.1	~0.1[k]	~0.3[k]	~1.0[k]	~0.1	~0.1	~1.0
• Post-TMI-2 Impacts: Internal (utility)[n]	~0.1	negligible[p]	~0.1	~0.1	negligible	~0.1	~0.1	~0.3
or								

Table 5.3-1 (Continued)

Decommissioning Element	DECON[c]	Prep. for Safe Storage[d]	SAFSTOR[e] 10 Years	SAFSTOR[e] 30 Years	SAFSTOR[e] 100 Years	ENTOMB[f] Internals Included (g)	ENTOMB[f] Internals Removed	100 years of Surveillance (h)
External (contractor)[o]	<0.1	negligible				<0.1	<0.1	
Subtotal (<5 rem/yr):								
Utility (Internal)	108.9	41.0	128.3	130.4	106.1	77.3	89.6	7.4
or								
Contractor (external) Staffing	131.8					96.2	112.8	7.4
TOTAL Estimated Cost:								
Utility Staffing	108.9		128.3	131.4	106.1	84.7	97.0	
or								
Contractor Staffing	131.8					104.3	120.2	

TABLE 5.3-1 Footnotes

(a) Values include a 25% contingency and are in constant 1986 dollars.

(b) Values exclude cost of disposal of last core, exclude cost of demolition of nonradioactive structures, and exclude cost of deep geologic disposal of dismantled, highly activated components.

(c) Adapted from Reference 1, Table 10.1-1, unless otherwise indicated.

(d) Adapted from Reference 1, Table 10.2-1, unless otherwise indicated.

(e) The values shown for SAFSTOR include the costs of the preparations for safe storage, continuing care, and deferred decontamination.

(f) Adapted from Reference 1, Table 10.3-1 and Appendix K.

(g) Does not include the eventual costs associated with the removal, packaging, and disposal of the entombed radioactive materials, the demolition of the entombment structure, or demolition of the Reactor Building.

(h) The annual cost of surveillance and maintenance for the entombed structure is estimated to be about $0.064 million.

(i) NA-not applicable.

(j) Adapted from Reference 1, Table 2.10-4.

(k) Adapted from Reference 1, Table J.7-2.

(l) Adapted from Reference 2, Table 1.1, unless otherwise indicated.

(m) The values shown include the estimated costs of NRC licensing activities as well as the costs associated with inspections anticipated to be required by other Federal and state agencies.

(n) Adapted from Reference 3, Table 2.5-7.

(o) Adapted from Reference 3, Table 2.5-7 and from Reference 1, Appendix O.

(p) Negligible means less than $0.025 million.

Table 5.3-2 Summary of radiation dose analyses for decommissioning the reference BWR (values are in man-rem)[a]

	DECON	SAFSTOR After			ENTOMB with	
		10 Years	30 Years	100 Years	Internals Included	Internals Removed
Occupational Exposure						
Safe Storage Preparation	NA[b]	294	294	294	NA	NA
Continuing Care	NA	1	7	10	neg	neg
Decontamination	1764	495	36	neg	NA	NA
Entombment	NA	NA	NA	NA	1492	1603
Safe Stor. Prep. Truck Shipments	NA	22	22	22	NA	NA
Decontamination Truck Shipments	110	22	2	neg	NA	NA
Entombment Truck Shipments	NA	NA	NA	NA	51	69
Total	1874	834	361	326	1543	1672
Public Exposure						
Safe Storage Preparation	NA	neg	neg	neg	NA	NA
Continuing Care	NA	neg	neg	neg	neg	neg
Decontamination	neg	neg	neg	neg	NA	NA
Entombment	NA	NA	NA	NA	neg	neg
Safe Stor. Prep. Truck Shipments	NA	2	2	2	NA	NA
Decontamination Truck Shipments	10	2	neg	neg	NA	NA
Entombment Truck Shipments	NA	NA	NA	NA	5	7
Total	10	4	2	2	5	7

[a] All entries are from Reference 1. Values exclude radiation dose from disposal of last core.

[b] NA means not applicable and neg means negligible.

about 110 man-rem.[a] In comparison, the average annual occupational radiation dose from operation, maintenance, and refueling of BWRs from 1974 through 1979 was approximately 670 man-rem per reactor[5] and 1,136 man-rem in 1980.

The inhalation radiation dose to the public from airborne radionuclide releases during DECON is estimated to be negligible. The radiation dose to the public from the truck transportation of radioactive wastes from DECON is estimated to be about 10 man-rem.

A major reason for the difference in cost and radiation dose between DECON of a BWR and a PWR is the requirement to dismantle, remove, and dispose of the radioactive turbine, condenser, and main steam piping of a BWR. A PWR turbine is not significantly contaminated with radioactivity since the major portion of the radioactivity is confined to the primary coolant systems.

5.3.2 SAFSTOR

Generally, the purpose of SAFSTOR is to permit residual radioactivity to decay to levels that will reduce occupational radiation exposure during subsequent, final decontamination. As indicated in Table 5.3-2, most of the occupational dose reduction due to decay occurs during the first 30 years after shutdown with considerably less dose reduction thereafter. The public dose will always be small and will also experiences most of its reduction during decommissioning within the first 30 years. Nonradioactive equipment and structures need not be removed, but eventually all radioactivity in excess of that allowed for unrestricted use of the facility must be removed. Hence, in contrast to DECON, to take advantage of the dose reduction, the safe storage period could be as long as 60 years including final decontamination. The end result is the same: release of the site and any remaining structures for unrestricted use.

SAFSTOR is advantageous in that it can result in reduced occupational radiation exposure in situations where urgent land use considerations do not exist. Disadvantages are that the owner is required to maintain a possession-only license under 10 CFR Part 50 during the safe storage phase and to meet its requirements at all times, thus contributing to the number of sites dedicated to radioactive materials storage for an extended time period. Other disadvantages are that surveillance and monitoring are required, the cumulative dollar costs are higher than for DECON, and the original operating staff will not be available at the end of the safe storage period to assist in the decontamination.

The PNL study shows that the costs of SAFSTOR for a 30-year period are greater than those of DECON and vary with the number of years of safe storage. For example, the total cost of 30-year SAFSTOR is estimated to be $131.4 million in 1986 dollars compared with the total cost of $108.9 million for DECON.

However, the total cost of 100-year SAFSTOR is estimated to $106.1 million in 1986 dollars. The lower cost of 100-year SAFSTOR compared to 30-year SAFSTOR is the result of lower costs for deferred decontamination due to the radio-

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[a] For a detailed explanation of the minor contributions (e.g., less than 0.08 man-rem for DECON) from post-TMI-2 impacts to the total estimates shown in Table 5.3-2, consult Table 2.4-2 of Reference 3.

activity having decayed. PNL's cost estimates for the decommissioning alternatives are presented in Table 5.3-1.

SAFSTOR results in lower radiation doses to both the work force and the public than DECON or ENTOMB. The aggregate occupational radiation dose is estimated to be approximately 337 man-rem for 30-year SAFSTOR (294 man-rem from safe storage preparation, 7 man-rem from continuing care, and 36 man-rem from deferred decontamination), not including transportation (Table 5.3-2). The occupational radiation dose from the truck transport of radioactive wastes is estimated to be about 24 man-rem. For 100-year SAFSTOR the estimated occupational radiation dose is estimated to be approximately 326 man-rem (294 man-rem from safe storage preparation, 10 man-rem from continuing care, and a negligible dose from deferred decontamination). The occupational radiation dose from the truck transport of radioactive wastes is estimated to be about 22 man-rem. Thus, 100-year SAFSTOR results in little additional reduction in the aggregate occupational radiation dose compared to 30-year SAFSTOR.

Radiation doses to the public from airborne radionuclide releases resulting from SAFSTOR are estimated to be negligible. The radiation dose to the public from the truck transport of radioactive wastes during the preparation for safe storage is estimated to be about 2 man-rem, and that from the truck transport of radioactive wastes during deferred decontamination after 30 and 100 years of safe storage is estimated to be negligible.

5.3.3 ENTOMB

ENTOMB means the complete isolation of radioactivity from the environment by means of massive concrete and metal barriers until the radioactivity has decayed to levels which permit unrestricted release of the facility. These barriers must prevent the escape of radioactivity and prevent deliberate or inadvertent intrusion. The length of time the integrity of the entombing structure must be maintained depends on the inventory of radioactive nuclides present. A BWR will contain ^{60}Co as the largest contributor to radiation dose. If it has been operated only a short time the integrity of the entombing structure need only be maintained for a few hundred years, as the disappearance of radioactivity is controlled by the 5.27-year half-life of ^{60}Co and the 30 year half-life fission products such as ^{137}Cs. If, on the other hand, the reactor has been operated for 30 or 40 years, substantial amounts of ^{59}Ni and ^{94}Nb (80,000-year and 20,000-year half-lives, respectively) will have been accumulated as activation products in the reactor vessel internals. The dose rate from the ^{94}Nb present in the reactor vessel internals has been estimated to be approximately 0.7 rem/hour while the dose from the ^{59}Ni in the internals is 0.07 rem/hour. These dose levels are substantially above acceptable residual radioactivity levels and, because of the long half-lives of ^{94}Nb and ^{59}Ni, would not decrease by an appreciable amount, due to radioactive decay, for thousands of years. In addition, there are an estimated 1,000 curies of ^{59}Ni in the reactor vessel internals which could result in potential internal exposures in the event of a breach of the entombed structure and subsequent introduction of the ^{59}Ni in an exposure pathway during the long half-life of ^{59}Ni. Thus, the long-lived isotopes will have to be removed or the integrity of the entombing structure will have to be maintained for many thousands of years.

ENTOMB for a BWR is limited to the containment vessel because its unique structure lends itself to entombment and because it contains most of the radioactivity in the facility. Other buildings associated with a reactor must be decommissioned by another method such as DECON. It is possible, however, to move some radioactive components from other buildings to the containment vessel and ENTOMB them there, rather than shipping them offsite.

ENTOMB is advantageous because of reduced occupational and public exposure to radiation compared to DECON, because little surveillance is required, and because little land is required. It is disadvantageous because the integrity of the entombing structure must be assured in some cases for hundreds of thousands of years, because a possession-only license under 10 CFR Part 50 would be required which in turn requires some surveillance, monitoring, and maintenance, and because entombing contributes to the number of sites dedicated to radioactive materials containment for very long time periods.

Two approaches to the ENTOMB alternative for a BWR are possible. In the first approach, the pressure vessel internals and their long-lived ^{59}Ni and ^{94}Nb isotopes are entombed, along with other radioactive material. This results in less cost and radiation dose because the pressure vessel and its internals will not have to be removed, dismantled, and transported to a deep geologic waste repository. It will also, however, result in the requirement for a possession-only license and indefinite surveillance because of the presence of the long-lived isotopes.

In the second approach, the pressure vessel internals, with their long-lived ^{59}Ni and ^{94}Nb isotopes, are removed, dismantled, and transported to a radioactive waste repository. This results in more cost and radiation dose, but offers the possibility that surveillance and the possession-only license could be terminated at some time within several hundred years, thereby releasing the entire facility for unrestricted use. At the outset, a careful inventory of radioactivity would need to be made to ensure that only relatively short-lived isotopes were present.

In both approaches, as much solid radioactive material from the entire facility as can be accommodated is sealed within the containment vessel. All openings to the exterior of the containment vessel are sealed. Radioactive material outside the containment vessel is removed down to levels which permit release of the remainder of the facility for unrestricted use.

Radioactive materials not entombed would have to be packaged and transported to a disposal site. Cost savings and radiation dose reductions would result from the lesser volume of radioactive equipment and material having to be dismantled, packaged, and transported. In any case, all spent fuel would be removed.

ENTOMB for the reference BWR, including the pressure vessel and its internals, is estimated to cost $77.3 million, with an annual surveillance and maintenance cost of $64,000. It results in an aggregate radiation dose of 1492 man-rem to decommissioning workers, 51 man-rem to transportation workers, and 5 man-rem to the general public. ENTOMB for the reference BWR, with the pressure vessel internals removed, is estimated to cost $89.6 million, with an annual surveillance and maintenance cost of $64,000, and to result in an aggregate radiation dose of 1603 man-rem to decommissioning workers, 69 man-rem to transportation

workers, and 7 man-rem to the general public. These estimates are listed in Tables 5.3-1 and 5.3-2.

5.3.4 Sensitivity Analyses

In addition to the reference BWR, PNL also analyzed a variety of realistic decommissioning situations.[1] These variations were studied to determine if they might have significant impact on the conclusions reached for the reference BWR regarding doses and costs for the decommissioning alternatives. While there were some differences in results, the conclusion of the sensitivity analysis is that these differences do not substantially affect the original cost and radiation dose conclusions. Of the various situations analyzed by PNL, the most important with regard to their potential effect on dose and cost estimates are reactor size, degree of contamination and type of containment structure.

Based on an analysis[6] similar to that for the reference BWR (NUREG/CR-0672) and incorporating selected cost adders (described in References 2 and 3 and escalated to constant 1986 dollars as shown in Table 5.3-1), upper-bound estimates were made of the costs for immediate dismantlement of reactor plants smaller than the reference plant. The analysis was limited to plants with thermal power ratings greater than 1200 MWt and was based on the assumption that all costs (staff labor, equipment, supplies, etc.) except radioactive waste disposal are independent of plant size. The results are shown in Table 5.3-3.

Table 5.3-3 Estimated immediate dismantlement costs (in millions) for plants smaller than the reference BWR, based on previously-derived overall scaling factors[a,b]

Reactor	MWt	Waste Disposal	Scaling Factor	Remaining Costs	Escalated Adders	Total Costs[c]
WNP-2	3320	44.201	1.000	54.464	10.230	108.894
Cooper	2381	44.201	0.809	54.464	10.230	100.453
Vermont Yankee	1593	44.201	0.648	54.465	10.230	93.336

[a] All costs are in constant 1986 dollars and include a 25% contingency.

[b] Derivation of previously-derived overall scaling factors can be found in Reference 1.

[c] Total costs shown above are for the utility-only cost option.

Using the results from Table 5.3-3, a linear equation can be derived for the scaling of the immediate dismantlement costs of plants in the 1200 to 3500 MWt range:

$$\text{Cost} = 78.993 + (9.008 \times 10^{-3})\ (\text{MWt})$$

Revised overall scaling factors for the Cooper and Vermont Yankee plants were obtained by dividing the results of the linear equation by the cost of the

reference plant. Based on this formula, a list of variations in dose and cost of these BWRs is presented in Table 5.3-4.

Also analyzed was the sensitivity of decommissioning costs and radiation doses to a postulated tripling of radiation dose rates from radionuclides deposited in BWR coolant system piping during reactor operation over a period of 30 to 40 years. This tripling of dose rate is postulated as an upper limit on the basis of recent trends for operating reactors. If no corrective action is taken to reduce the radiation dose rates, the accumulated radiation dose to decommissioning workers for DECON would be increased from 1764 man-rem to 4573 man-rem,[1] and the total decommissioning costs could be increased by about 12 million for DECON. For ENTOMB the radiation dose would be increased from 1604 man-rem to 4154 man-rem and the total cost could be increased about 12 million. For preparation for safe storage, the radiation dose would be increased from 294 man-rem to 759 man-rem, and there would be no significant change in the cost.

In order to handle these postulated higher initial radiation levels, it appears that additional chemical decontamination during decommissioning would be the most cost-effective approach. For example, it is estimated that increasing the circulation time of the chemical solution about 50% would reduce the postulated increased radiation levels by a factor of 3, thus reducing these levels to approximately the same dose rate conditions assumed in the reference case analysis. This approach would also be more consistent with the principles of ALARA, since the occupational radiation dose associated with a chemical decontamination cycle is relatively small, compared with the radiation dose associated with installing temporary shielding, or with attempting to perform the dismantlement without additional shielding. In addition, it appears likely that the large buildups of radionuclides prevalent today on piping systems will be prevented as periodic decontamination during normal operation of the reactor coolant system and related fluid-handling systems becomes standard procedure.

Analysis was also done to determine if variation in design of the BWR containment structure would have significant impact on doses or costs of decommissioning. There are three principal designs of BWR containments and pressure suppression systems, namely Mark 1, Mark II, and Mark III and these were analyzed by PNL. The conclusion reached by this analysis was that for BWR plants of equivalent power rating, differences in containment design have very little effect on the total cost of decommissioning of a BWR.

One of the circumstances that has changed since the original BWR decommissioning report[1] was prepared which could influence the development of the cost of dose estimates presented in this GEIS is an assessment of post-TMI-2 requirements on the decommissioning of the reference BWR. Actions judged necessary by the NRC to correct or improve the regulation and operation of nuclear power plants based on the experience from the accident at TMI-2 resulted in a number of recommendations that were subsequently issued to the utilities as requirements. Some of those requirements resulted in equipment and hardware changes and/or additions to the reference BWR that could eventually expand the scope of decommissioning activities, since those materials could reasonably be expected to become contaminated or radioactive during the remaining operational lifetime of the plant. For the reference BWR, it was concluded by PNL in a recent study[3] that the original immediate dismantlement decommissioning cost estimates could be expected to increase very slightly overall (considerably less than 1% in

Table 5.3-4 Estimated costs and occupational radiation doses for decommissioning different-sized BWR plants (a, b, c)

		Station		
		Vermont Yankee	Cooper	WNP-2
Power Rating	(thermal megawatts)	1,593	2,381	3,320
Overall Scaling Factor	(OSF)	0.857	0.922	1.000
DECON	($millions)	93.3	100.4	108.9
	(man-rem)	1,581	1,701	1,845(c)
ENTOMB(d)				
w/internals	($ millions)(c)	66.2	71.3	77.3
	(man-rem)	1,348	1,450	1,573
w/o internals	($ millions)	76.8	82.6	89.6
	(man-rem)	1,443	1,553	1,684
SAFSTOR				
Preparations for Safe Storage	($ millions)	35.1	37.8	41.0
	(man-rem)	321	346	375
Safe Storage:				
for 30 years	($ millions)	3.3	3.3	3.3
	(man-rem)	6.5	6.5	6.5
for 50 years	($ millions)	5.6	5.6	5.6
	(man-rem)	10	10	10
for 100 years	($ millions)	11.7	11.7	11.7
	(man-rem)	10	10	10
Deferred Dismantlement:				
after 30 years	($ millions)	70.4	75.8	82.2
	(man-rem)	31	33	36
after 50 years	($ millions)	41.4	44.5	48.3
	(man-rem)	2.6	2.8	3
after 100 years	($ millions)	41.1	44.3	48
	(man-rem)	>1	>1	>1
Facility Demolition	($ millions)	16.4	18.0	19.9

(a) Values include a 25% contingency and are in 1986 dollars.

(b) Costs do not include spent-fuel disposal or demolition of nonradioactive structures.

(c) Doses are taken from Reference 1 and do not include those due to transportation of wastes.

(d) ENTOMB costs do not include continuing care costs (0.064 M/yr).

constant 1986 dollars), due to a slightly expanded scope of decommissioning activities associated with changes in the reference plant's characteristics. The radiation dose would be increased by about 3 man-rem, due entirely to decommissioning operations associated with the removal and packaging of a small additional quantity of contaminated materials.

Other methods of facilitating decommissioning, in addition to additional chemical decontamination, are discussed in NUREG/CR-0569.[7] These include improved documentation, reduction of radwaste volume by incineration, electropolishing of piping and components as a decontamination technique, remote maintenance and decommissioning equipment (robots), improved access to piping and components, and improved concrete protection.

5.4 Environmental Consequences

Radiation doses and costs associated with possible decommissioning alternatives are discussed in Section 5.3. It is to be emphasized for perspective that for any viable decommissioning alternative, the environmental effects of greatest concern, i.e., radiation dose and radioactivity released to the environment, are substantially less than the same effects resulting from reactor operation and maintenance. It should also be noted that while the dollar costs of ENTOMB are less than those of DECON, the environmental impacts could be quite high should large amounts of radioactivity escape from a breached structure during the entombment period.

Other environmental consequences are rather different from the environmental consequences usually discussed in environmental impact statements. This is because, usually, an environmental impact statement is addressed to the consequences of building a facility that will require land, labor, capital investment, materials, continuing use of air, water and fuel, a socioeconomic infrastructure, etc. Decommissioning, on the other hand, is an attempt to restore things to their original condition, which requires a much smaller commitment of resources than did building and operating the facility.

A major environmental consequence of decommissioning, other than radiation dose and dollar cost, is the commitment of land area to the disposal of radioactive waste. Estimates are shown in Table 5.4-1 of the low-level waste disposal volume required to accommodate radioactive waste and rubble removed from the facility and transported to a licensed site for disposal. The volume for ENTOMB does not include the volume of the entombing structure or of the wastes entombed within it, only the wastes shipped off-site. The entombing structure is, in effect, a new radioactive waste burial ground, separate and distinct from the ones in which the wastes in Table 5.4-1 are buried, and may necessitate licensing consideration such as those for a low-level waste burial ground under (10 CFR 61).

If shallow-land burial of radioactive wastes in standard trenches is assumed, then a burial volume of about 18,975 m^3 of radioactive waste can be accommodated in less than 2 acres. The two acres is small in comparison with the 1,160 acres used as the site of the reference BWR.

Certain highly activated components of the reactor and its internals may require disposal in a deep geologic disposal facility rather than in a shallow-land burial ground because of the large initial level of radioactivity and the very

Table 5.4-1 Estimated burial volume of low-level radioactive waste and rubble for the reference BWR

Decommissioning Alternative		Volume (m^3)
DECON		18,975[a]
SAFSTOR		
Deferred Decontamination[b] following Safe Storage for:	10 Years	18,975[a,c]
	30 Years	18,975[a,c]
	50 Years	1,783
	100 Years	1,673
ENTOMB[d]		
Internals Included		8,042
Internals Removed		8,420

[a] Includes about 36m^3 of radioactive waste attributable to removal of backfitted material (adapted from Table 5.2-8, Reference 3).

[b] Radioactive wastes from preparations for safe storage are small in comparison to those from deferred decontamination.

[c] Although, in actuality, there is a gradual decrease in waste volume over time, it is not indicated here for clarity of presentation.

[d] Volume of entombing structure and the wastes within are not included.

long half-lives of ^{59}Ni and ^{94}Nb. Only about 11.5 m^3 of material would be involved and would require approximately 89 m^3 of waste disposal space.

The cost for disposing of these materials in deep geologic disposals was estimated by PNL to be about $2.9 million (in 1978 dollars).[1] Based on recent estimates of deep geologic disposal costs,[8] it is currently estimated by PNL that deep geologic disposal of the highly activated materials would cost about 16.2 million (in 1986 dollars). This cost has not been included in the costs of decommissioning shown in Table 5.3-1.

PNL considered accidental releases of radioactivity both during decommissioning during transport of wastes and the results are presented in Table 5.4-2. Radiation doses to the maximally-exposed individual from accidental airborne radioactivity releases during decommissioning operations were calculated to be quite low. Radiation doses to the maximally-exposed individual from accidental radioactivity releases resulting from transportation accidents were calculated to be low for the most severe accident.

Other environmental consequences of decommissioning are minor compared to the environmental consequences of building and operating a BWR. Water use and evaporation at the rate of as much as 27×10^6 m^3/yr ceased when the reactor ceased operation. The total water use for decommissioning is estimated to be about 18×10^3 m^3. The number of workers on site at any time will be no greater than when the BWR was in operation and will be much less than when the BWR was under construction. The transportation network is already in place, but will require some maintenance if the SAFSTOR mode is selected.

Disturbance of the ground cover need not take place to any appreciable extent except for filling holes and leveling the ground following removal of underground structures, unless operation of the plant has resulted in contamination of the ground around the plant. Plowing of the ground would generally result in lowering average soil contamination levels to those acceptable for releasing the site for unrestricted use, except for a few more highly contaminated areas where materials would have to be removed. In this case, soil to depth of several centimeters and some paving may have to be removed, packaged, and shipped to a disposal facility before the site can be released for unrestricted use.

The biggest socioeconomic impact will have occurred before decommissioning started, at the time the plant ceased operation and the tax income created by the plant was reduced. No additional public services will be required because the decommissioning staff will be somewhat smaller than the operating staff. In the case of deferred decontamination, the decontamination staff will be larger than the surveillance staff.

5.5 Comparison of Decommissioning Alternatives

From careful examination of Tables 5.3-1 and 5.3-2 it appears that DECON or 30-year SAFSTOR are reasonable options for decommissioning a BWR. 100-year SAFSTOR is not considered a reasonable option since it results in the continued presence of a site dedicated to radioactivity containment for an extended time period with little benefit in aggregate dose reduction compared to 30-year SAFSTOR. DECON costs less than SAFSTOR and its larger on an annual basis occupational radiation dose, which is consistent with routine annual operational

Table 5.4-2. Summary of radiation doses to the maximally-exposed individual from accidental airborne radionuclide releases during BWR decommissioning and transportation of wastes

Incident	Total Atmospheric Release (Ci/hr)(b)	Radiation Dose to Lung (in rem) from: DECON		SAFSTOR		ENTOMB		Occurrence(a)
		First-Year	Fifty-Year	First-Year	Fifty-Year	First-Year	Fifty-Year	
Severe Transportation Accident	2.0×10^{-2}	9.0×10^{-2}	2.0×10^{-1}	9.0×10^{-2}	2.0×10^{-1}	9.0×10^{-2}	2.0×10^{-1}	Low
Explosion of LPG Leaked from a Front-end Loader	8.6×10^{-3}	7.9×10^{-5}	1.5×10^{-4}	N/Ac	N/A	N/A	N/A	Low
Vacuum Filter-Bag Rupture	8.5×10^{-4}	8.3×10^{-5}	1.8×10^{-4}	8.3×10^{-5}	1.8×10^{-4}	8.3×10^{-5}	1.8×10^{-4}	Medium
Minor Transportation Accident	5.0×10^{-4}	2.2×10^{-3}	4.5×10^{-3}	2.2×10^{-3}	4.5×10^{-3}	2.2×10^{-3}	4.5×10^{-3}	Low
Contamination Control Envelope Rupture	1.4×10^{-4}	1.0×10^{-6}	1.9×10^{-6}	N/A	N/A	N/A	N/A	High
Oxyacetylene Explosion	1.2×10^{-4}	8.7×10^{-7}	1.6×10^{-6}	N/A	N/A	N/A	N/A	Medium
Contaminated Sweeping Compound Fire	1.1×10^{-6}	1.1×10^{-7}	2.3×10^{-7}	1.1×10^{-7}	2.3×10^{-7}	1.1×10^{-7}	2.3×10^{-7}	Medium
Gross Leak During Loop Chemical Decontamination	1.0×10^{-6}	9.8×10^{-8}	2.1×10^{-7}	9.8×10^{-7}	2.1×10^{-7}	9.8×10^{-8}	2.1×10^{-7}	Low
Filter Damage from Blasting Surges	1.3×10^{-7}	1.2×10^{-9}	N/A	N/A	N/A	N/A	N/A	Medium

Table 5.4-2 (Continued)

Incident	Total Atmospheric Release (Ci/hr)(b)	Radiation Dose to Lung (in rem) from: DECON First-Year	DECON Fifty-Year	SAFSTOR First-Year	SAFSTOR Fifty-Year	ENTOMB First-Year	ENTOMB Fifty-Year	Occurrence(a)
Combustible Waste Fire	6.0×10^{-9}	5.9×10^{-10}	1.2×10^{-9}	5.9×10^{-10}	1.2×10^{-9}	5.9×10^{-10}	1.2×10^{-9}	High
Detonation of Unused Explosives	4.8×10^{-10}	4.4×10^{-12}	8.6×10^{-12}	N/A	N/A	N/A	N/A	Medium

(a) The frequency of occurrence considers not only the probability of the accident, but also the probability of an atmospheric release of the calculated magnitude. The frequency of occurrence is listed as "high" if the occurrence of a release of similar or greater magnitude per year is $>10^{-2}$, as "medium" if between 10^{-2} and 10^{-5}, and as "low" if $<10^{-5}$.

(b) All atmospheric releases are assumed to occur during a 1-hr period, for comparison purposes.

(c) N/A = Not applicable.

dose for plant operations is considered of marginal significance to health and safety.

Either ENTOMB option requires indefinite dedication of the site as a radioactive waste burial ground. In the ENTOMB option with the reactor internals and its long-lived activation products entombed, the security of the site could not be assured for thousands of years necessary for radioactive decay, so this option is not considered viable. In the ENTOMB option with the reactor internals removed, it may be possible to release the site for unrestricted use at some time within the order of a hundred years if calculations demonstrate that the radioactive inventory has decayed to acceptable residual levels. However, even this ENTOMB alternative appears to be less desirable than either DECON or SAFSTOR based on consideration of the fact that ENTOMB results in higher radiation exposure and higher initial costs than 30-year SAFSTOR, that the overall cost of ENTOMB over the entombment period is approximately the same as DECON, and the fact that regulatory changes occurring during the long entombment period might result in additional costly decommissioning activity in order to release the facility for unrestricted use.

Consideration was given to the situation where, at the end of the reactor operational life, it is not possible to dispose of waste offsite for a limited period of time, but not exceeding 100 years (see Section 2.7). Such a constraint needs to be accounted for in selecting the decommissioning alternative. Based on an analysis by PNL of the technology, safety and cost considerations on selection of decommissioning alternatives,[9] it was concluded that SAFSTOR is an acceptably viable alternative. Unlike the PWR case, DECON and conversion of the spent fuel pool to an independent spent fuel storage pool for a BWR is an unlikely possibility for the case where all other radioactive wastes can be removed offsite. The active phase of maintaining the spent fuel in the pool is not considered to be part of the regulatory requirements for decommissioning, but would be considered under the usual operating licensing aspects regarding health and safety with consideration given to facilitation for decommissioning. Aside from the expenses incurred from storing spent fuel, other costs for keeping radioactive wastes onsite for the reactor in a safe storage mode were estimated to have minimal effect on the SAFSTOR alternative compared to this alternative for radioactive wastes being sent offsite. Site security for storage of spent fuel (which is considered as an operational rather than a decommissioning consideration) was estimated at about $0.94 million per year (in 1986 dollars)[(a)]. For a multi-reactor site, such security could result in a lesser cost because of a sharing of required overheads.

[(a)] Adapted from Reference 9.

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*See footnote to reference in Chapter 1 for document purchasing availability.